SPACE STATION EVOLUTION

BEYOND THE BASELINE

TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE

Uwe Hueter
NASA Marshall Space Flight Center

Doug Comstock
General Dynamics Space Systems Division

South Shore Harbour Resort and Conference Center
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MSFC SUPPORTING STUDIES FOR TRANSPORTATION NODE

- Proximity Operations
- Debris Protection
- Orbital Operations
- Station Logistics
- $\boxed{\text{• Transfer Vehicle Accomodations}}$

TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
Infrastructure Study - General Dynamics (Contract NAS8-37588)

Study Task Manager:	Doug Comstock
Concept Development:	Kyle Shepard
Operations Analysis:	Brián Emmett
Economic Analysis:	Penny Burnstein
Technology:	John Maloney

TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
Outline

- INTRODUCTION
- REQUIREMENTS
- LUNAR TRANSFER VEHICLE ACCOMMODATIONS
- MARS TRANSFER VEHICLE ACCOMMODATIONS
- CONCLUSIONS

TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
Introduction

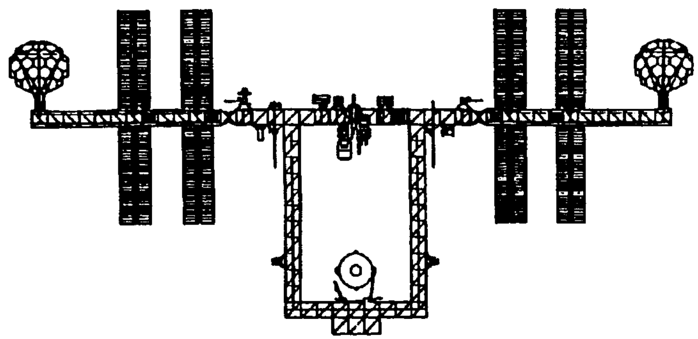
There are three primary objectives of this study. The first is to identify time-phased accommodation capabilities necessary to support the civil space exploration initiatives. These initiatives include the Lunar and Mars missions in the Human Exploration Initiative (HEI). Primary accommodation requirements include integration and assembly of vehicle components and systems on-orbit, and protection of these vehicles from the space environment, particularly debris.

Secondly, this study will develop accommodation concepts, define impacts (hooks and scars) to Space Station Freedom (SSF), identify staging/servicing requirements, and identify required technology advances.

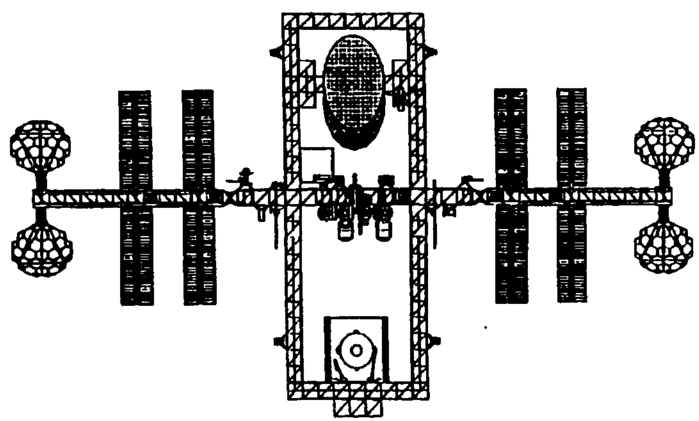
Finally, the majority of the study effort has been devoted to conducting a trade study to evaluate alternative transfer vehicle accommodation concepts. These concepts have ranged from basing all transfer vehicle accommodations for both Lunar and Mars transfer vehicles at SSF, to basing all accommodation capabilities off SSF.

Shown below are two steps in the NASA reference SSF evolution process. The first configuration is to provide lunar transfer vehicle (LTV) accommodation support, and the second is to provide accommodations support for the Mars transfer vehicle (MTV).

TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
Introduction



LUNAR TRANSFER VEHICLE ACCOMMODATIONS
SSF Evolution Reference



MARS TRANSFER VEHICLE ACCOMMODATIONS
SSF Evolution Reference

PRIMARY STUDY OBJECTIVES

- IDENTIFY TIME-PHASED ACCOMMODATION CAPABILITIES NECESSARY TO SUPPORT THE ACCOMPLISHMENT OF CIVIL SPACE EXPLORATION INITIATIVES
- DEVELOP ACCOMMODATION CONCEPTS, DEFINE IMPACTS TO SPACE STATION FREEDOM (HOOKS AND SCARS), IDENTIFY STAGING/SERVICING REQUIREMENTS, AND IDENTIFY REQUIRED TECHNOLOGY ADVANCES
- CONDUCT A TRADE STUDY TO EVALUATE ALTERNATIVE TRANSFER VEHICLE ACCOMMODATION CONCEPTS, PRIMARILY SPACE STATION BASED VERSUS A SEPARATE FREE-FLYING FACILITY

TRANSFER VEHICLE ACCOMMODATION OPTIONS SUMMARY

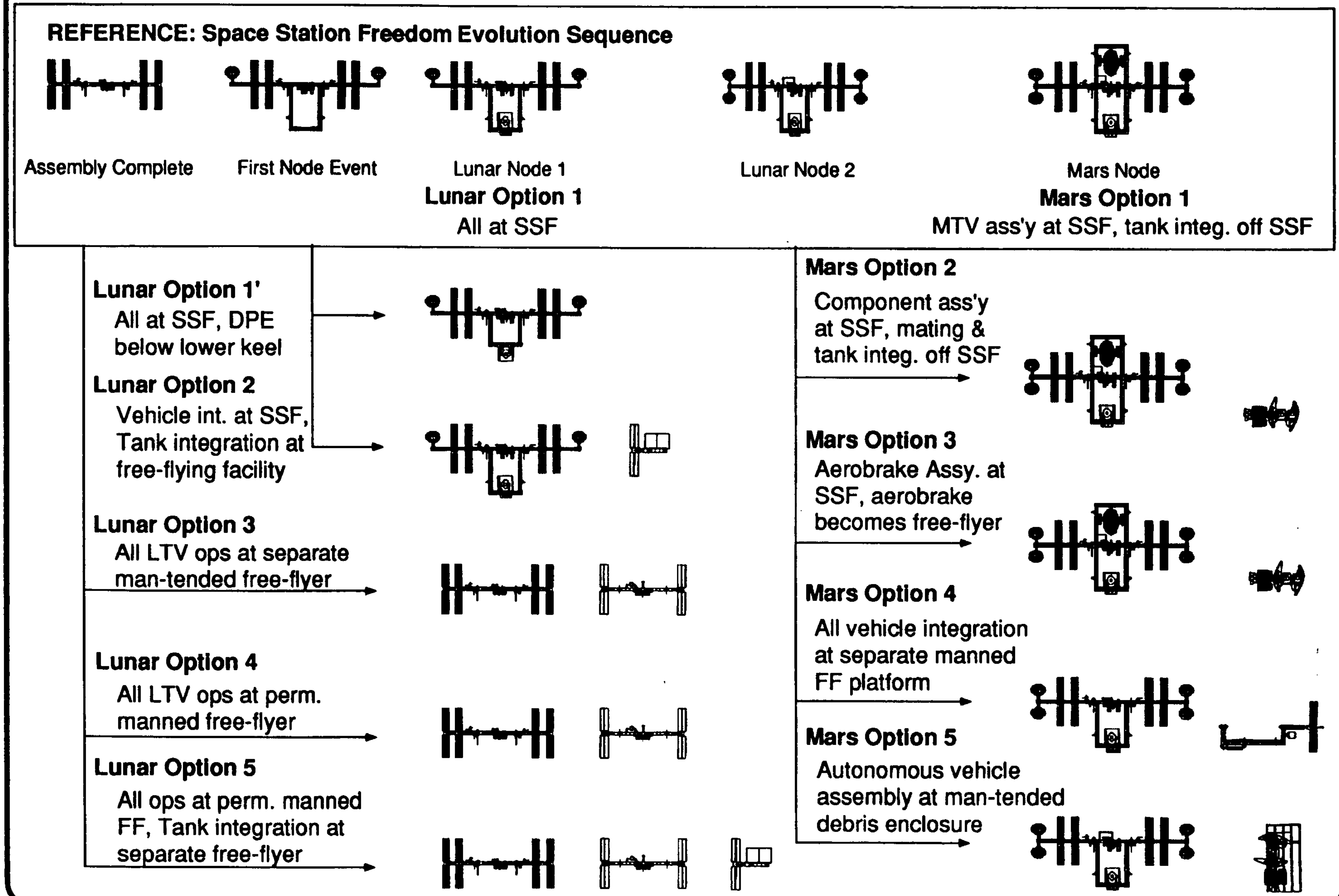
There are two primary requirements of on-orbit accommodations facilities. The first is to support a Lunar transfer vehicle (LTV), the second a Mars transfer vehicle (MTV). There is a large difference in size and accommodation requirements for these two vehicles.

In conducting the trade study for basing accommodations at the space station or at a free-flying node, several options were developed. Alternative options were developed as branches to the SSF reference evolution sequence as defined by NASA. The NASA reference has all accommodations at SSF, and the options considered in the trade study for Lunar and Mars vehicles have varying degrees of operations performed away from SSF.

The first branch off of the reference evolution departs from the assembly complete station, to develop free-flying accommodation facilities. The second branch departs from the first node event, and includes an alternative to the all at SSF basing and the free flying tank integrator. The third branch is for Mars accommodations and assumes that SSF has evolved through the reference path to the lunar node 2 configuration. From this configuration, alternatives to basing at SSF are considered including various assembly and integration operations using SSF to a lesser degree, and concepts which are independent of the SSF for assembly and integration.

The alternative (Option 1') to all at SSF basing (Option 1) places the debris protection enclosure below the cross members of the lower keel truss assembly. This option provides easier access to the interior of the debris protection enclosure, and eases some of the operations requirements for assembly of the aerobrake and integration of the propellant tanks at the station.

TRANSFER VEHICLE ACCOMMODATION OPTIONS SUMMARY



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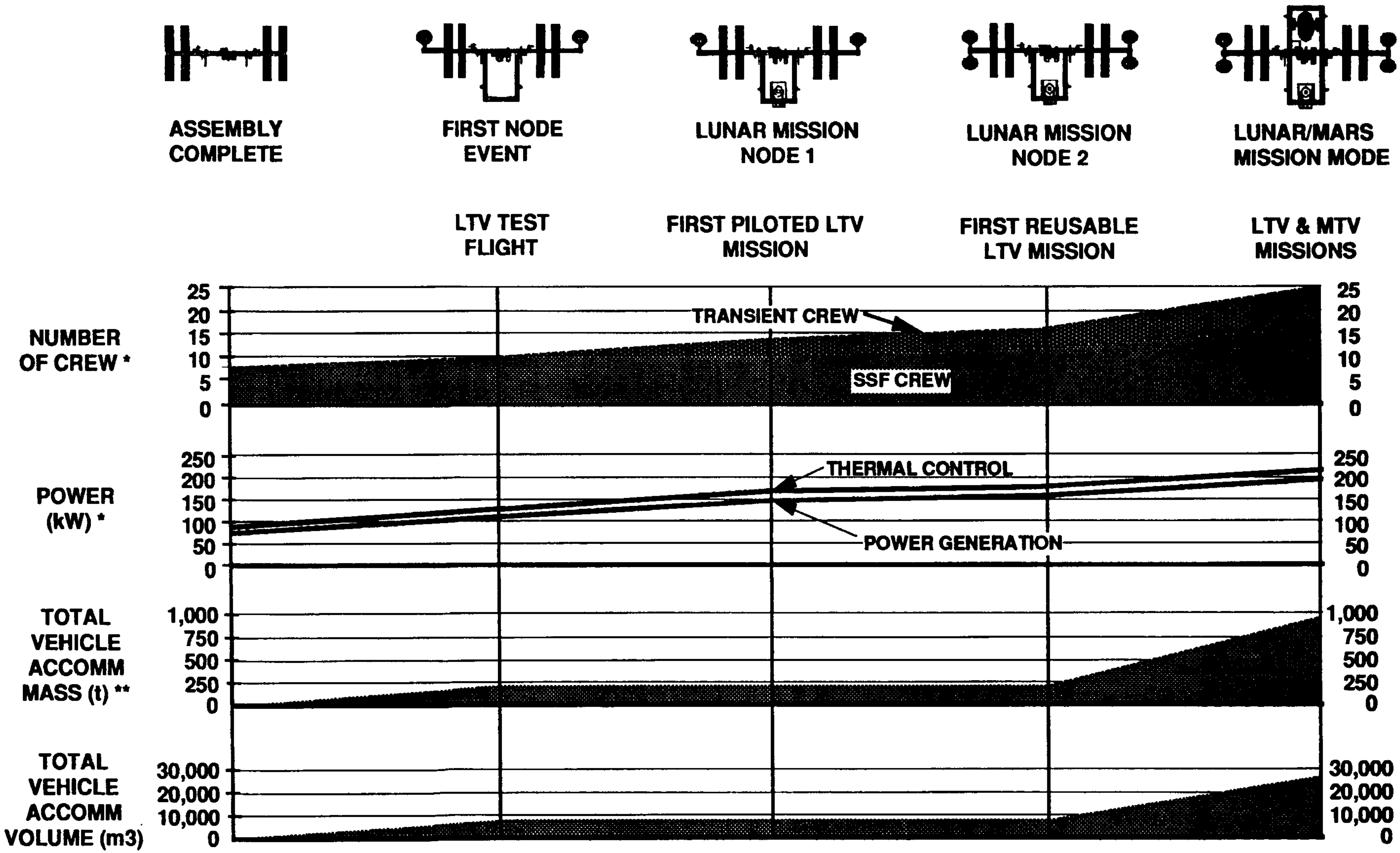
SPACE STATION FREEDOM EVOLUTION
Transfer Vehicle Accommodation Support Requirements

Support requirements have been defined for SSF to support evolution to accommodate LTV and MTV operations. These requirements see the number of crew rise from 8 at Assembly Complete (AC) to 25 at completion of the MTV accommodations, 9 of which are transient crew.

Power generation and thermal control requirements increase with the addition of accommodation capabilities at the station, as shown. The mass of the vehicles to be accommodated increases from 0 to 216 metric tonnes for the LTV test flight. Addition of the MTV at 774 metric tonnes brings the total to 990 metric tonnes.

The volume of the vehicles which must be accommodated in the debris protection enclosure begins at 6,300 cubic meters for the LTV. With the addition of the MTV at 20,000 cubic meters, the total increases to 26,300 cubic meters.

SPACE STATION FREEDOM EVOLUTION
Transfer Vehicle Accommodation Support Requirements



SOURCE: * NASA, "Report of the 90-day study on Human Exploration of the Moon and Mars", November 1989
** NASA, LaRC SSFO, "Space Station Accommodation of Human Exploration Program Initiative Block II Reference Mission Requirements, Final Implementation", 24 September 1989

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TRANSFER VEHICLE ACCOMMODATIONS
Incremental Time Phased Requirements

The requirements placed on an orbital transfer vehicle accommodation facility are phased over time, to reflect the maturity of the exploration program and the vehicles involved. There are three steps in the LTV accommodation growth: LTV test flight, a piloted LTV flight and a reusable flight.

The LTV test flight will require the node to support LTV delivery, docking at the node, payload transfer, component assembly, vehicle integration, prelaunch checkout, and launch.

The first piloted LTV flight will require capabilities of the node in addition to those required for the test flight. These capabilities include debris protection, transient crew accommodations, retrieval of the LTV upon return from the moon, and post-mission checkout.

The first reusable LTV flight will require a servicing and maintenance capability, and a long term storage of the LTV at the node between next lunar missions.

MTV accommodations begin several years after LTV accommodations have started. The MTV accommodations are in addition to the accommodations for the LTV. Support for the first MTV mission will require capabilities at the node for MTV delivery, docking at the node, payload transfer, debris protection, component assembly, vehicle integration, transient crew accommodations, prelaunch checkout, and launch of the vehicle.

The MTV carrying the Mars crew returns to the node about four years after initial capabilities for MTV assembly and integration have been in place. Additional capabilities which must available at the node at this time include retrieval of the returning MTV, post-mission checkout, servicing and maintenance of the crew module, and long term storage of the crew module until the next Mars mission.

TRANSFER VEHICLE ACCOMMODATIONS
Incremental Time Phased Requirements

LUNAR TRANSFER VEHICLE

LTV Test Flight	First Piloted LTV Flight	First Reusable LTV Flight
• LTV DELIVERY • DOCKING AT NODE • PAYLOAD TRANSFER • COMPONENT ASSEMBLY • VEHICLE INTEGRATION • PRELAUNCH CHECKOUT • LAUNCH	• DEBRIS PROTECTION • TRANSIENT CREW ACCOMMODATIONS • RETRIEVAL OF LTV • POST-MISSION CHECKOUT	• SERVICING / MAINTENANCE OF LTV • LONG TERM STORAGE OF LTV

MARS TRANSFER VEHICLE*

First MTV Flight	First MTV Return
• MTV DELIVERY • DOCKING AT NODE • PAYLOAD TRANSFER • DEBRIS PROTECTION • COMPONENT ASSEMBLY • VEHICLE INTEGRATION • TRANSIENT CREW ACCOMMODATIONS • PRELAUNCH CHECKOUT • LAUNCH	• RETRIEVAL • POST-MISSION CHECKOUT • SERVICING/MAINTENANCE OF CREW MODULE • LONG TERM STORAGE

* Mars Transfer Vehicle Capabilities are in addition to Lunar Transfer Vehicle Capabilities, which are ongoing in parallel.

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TRANSPORTATION NODE LTV SUPPORT CAPABILITY
Varying Lunar Surface Stay, Launch Rates & Assembly Times

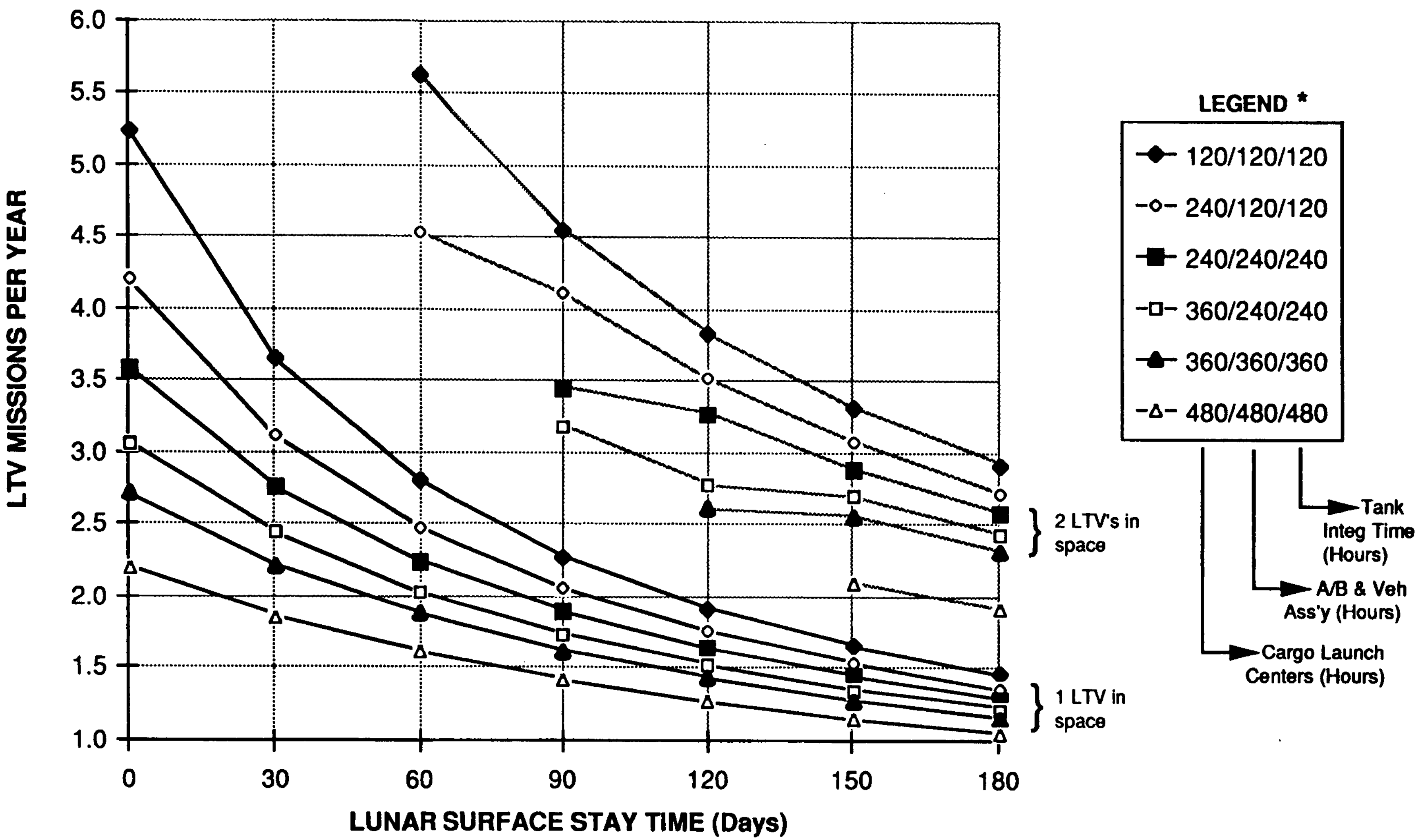
The maximum LTV flight rates that can be supported by a transportation node are shown on this chart as a function of the Lunar surface stay time of the mission, the launch rates of the Earth to orbit (ETO) cargo vehicles, and the duration of the aerobrake and vehicle assembly and the propellant tank integration operations taking place at the node. These capabilities assume that there are on-orbit accommodations for only one LTV at a time.

The shaded lines (upper group) represent the increase in capability when two LTVs are available. One LTV is at the accommodation facility while the other is on a mission. This option is limited by the duration of the mission (Lunar surface stay time). This option considered feasible only if the total time required at the facility is less than the mission duration.

For any of these options, the region above the line indicates a requirement to have multiple accommodations at the node in order to support the LTV flight rate. The region below the curve indicates that the flight rate requirement is satisfied with a single accommodation facility.

LTV flight rate requirements for the current mission options can be supported by a single accommodation facility.

TRANSPORTATION NODE LTV SUPPORT CAPABILITY
Varying Lunar Surface Stay, Launch Rates & Assembly Times



ASSUMPTIONS:
- reusable LTV - 5 flights
- Only one LTV at accommodation facility at a time
- LTV stays in LLO during surface stay

* Assuming One 8 Hour Shift/Day

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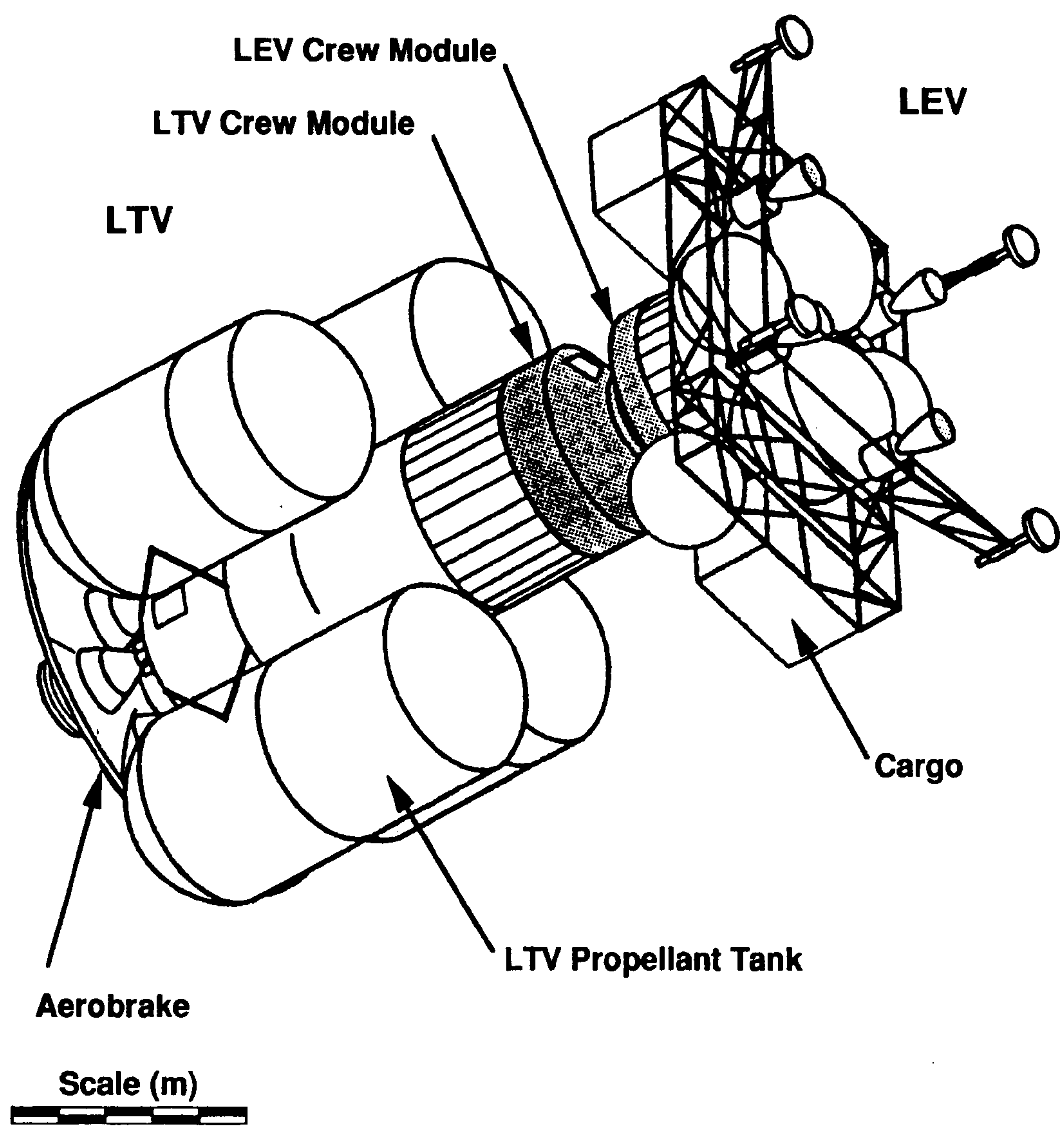
LUNAR TRANSFER VEHICLE
Vehicle Description

The baseline Lunar Transfer Vehicle /Lunar Excursion Vehicle (LTV/LEV) design used during this analysis is shown below. This is the all cryogenic aerobraked version capable of delivering 25.6t of cargo to the lunar surface in a reusable mode.

The LTV consists of three major components: a large expendable tankset (4.4m dia x 9.9m long), a smaller expendable tankset (4.4m dia x 6.5m long), and a central core with aerobrake (7.6m dia x 12.2m long). Because the aerobrake is 13.7m in diameter, on-orbit assembly is required. The LEV is delivered in a single piece that packages into 7.6m dia x 6.8m long.

If a piloted mission is required an LTV and LEV crew modules are used. These components are 4m and 2.8m long respectively, and 4.5m in diameter. Mass properties are shown below.

LUNAR TRANSFER VEHICLE
Vehicle Description



TYPICAL DELIVERY SEQUENCE:
3 Launches

1) LTV, LEV & Payload (STS-C')
2) LTV Propellant Tanks (2) (STS-C)
3) LTV Propellant Tanks (2) (STS-C)

LTV MASS PROPERTIES SUMMARY (t)

LTV	158.3
CORE	22.7
Inert	8.1
Crew Module	7.6
Propellant	7.0
PROP TANKS	135.6
Inert	5.8
Propellant	129.8
LEV	31.8
Inert	5.8
Crew Module	3.6
Propellant	22.4
CARGO	25.6
TOTAL	215.7

Source: NASA, "Report of the 90-day study on Human Exploration of the Moon and Mars", November 1989

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TYPICAL LUNAR MISSION SCENARIO
Transportation Node / Infrastructure Element Interfaces

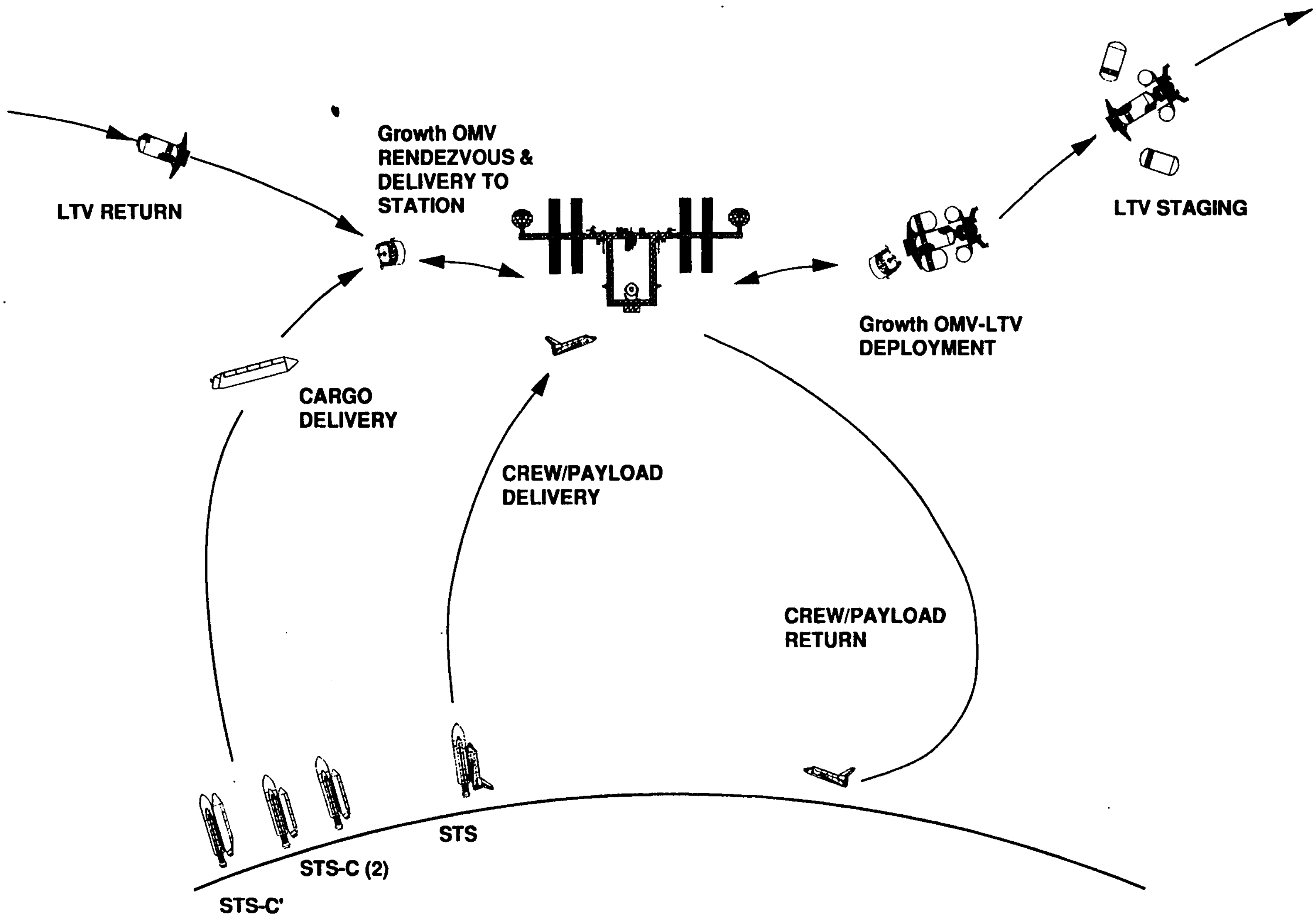
There are several infrastructure elements which must interface with the transportation node in support of a typical lunar mission scenario. These elements include ETO cargo and crew delivery vehicles, vehicles to provide transportation between cargo vehicles or returning spacecraft and the node, and the interface with the LTV for assembly, integration, and maintenance.

ETO cargo vehicles can have a significant impact on the operations at the transportation node. This is a function of the lift capability and the geometric cargo envelope of the vehicle. These factors affect the amount of vehicle assembly that must be done because of element sizing, and the number of elements, particularly propellant tanks that must be delivered and integrated on-orbit. The ETO vehicles considered are the STS-C (used for propellant delivery) with a 71t lift capability and a 4.6m dia payload carrier, and the STS-C' (used for vehicle and aerobrake delivery) with a 61t lift capability and a 7.6m dia payload carrier.

The transfer of cargo between the ETO vehicle and the node is performed by a growth version of the orbital maneuvering vehicle (OMV). The capabilities of the growth OMV are determined by the lift capability of the ETO vehicle, and the size of the cargo it delivers. For the defined cargo vehicles, the growth OMV must have the capability to transfer a 71t payload and see around a 7.6m diameter payload.

Crew delivery and return, and some payload delivery and return are performed by the STS.

TYPICAL LUNAR MISSION SCENARIO
Transportation Node / Infrastructure Element Interfaces



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LTV ACCOMMODATIONS OPTIONS

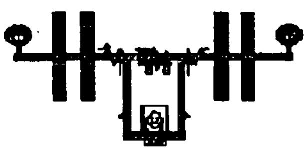
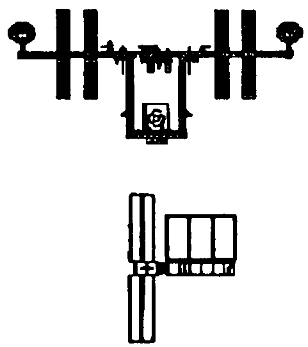
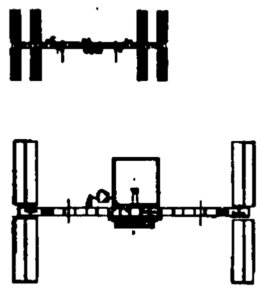
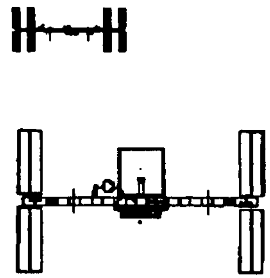
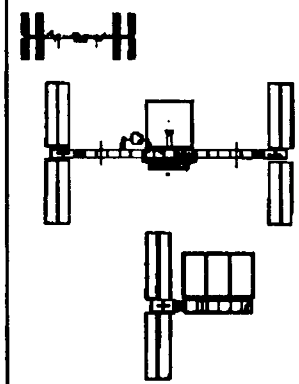
Five primary transportation node concepts have been identified for Lunar Transfer Vehicle (LTV) accommodations. These configurations range from those utilizing an evolved SSF to a node separate from SSF for vehicle integration and assembly.

Options one and two are based on evolving the current SSF into a transportation node. These two options are similiar with the variable being the degree of operational and safety impacts associated with integrating the LTV propellant tanks at SSF.

Option three and four are free flying platform at which vehicle components are assembled and integrated. Scenario 4 is manned and Scenario 3 is man-tended. The LTV is assembled and integrated in a debris protection enclosure at the node. There are no operational impacts to the SSF with the permanently manned option.

Option five is similiar to options three and four with the difference being an additional free flying platform for tank integration.

LTV ACCOMMODATION OPTIONS

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5
	ALL ACCOMMODATIONS AT SSF	ACCOMM AT SSF, WITH FREE FLYING PROP INTEG FACILITY	ACCOMM AT MAN-TENDED FREE FLYING PLATFORM	ACCOMM AT PERM MANNED FREE FLYING PLATFORM	PERM MANN FF WITH FREE FLYING PROP INTEG FACILITY
CONFIGURATION					
DESCRIPTION	All accommodations for option 1 are based at SSF. A drop-keel with a debris protection enclosure (DPE) and additional power modules are the primary additions to the AC station.	Option 2 utilizes a small unmanned free flying node for propellant tank integration. The additions to SSF from Option 1 enable all assembly and integration except for tanks to be done at SSF.	A man-tended free-flying transportation node is used for Option 3. All on-orbit assembly and integration is done at the free-flyer. Crew is delivered from SSF. Hardware for the free-flyer is SSF derived.	A permanently manned free-flying transportation node is used for Option 4. All on-orbit assembly and integration is done at the free-flyer. Hardware for the free-flyer is SSF derived.	Option 5 utilizes a small unmanned free flying node for propellant tank integration. All assembly and integration except for tanks is done at the free-flying node shown in Option 4.
MASS PROPERTIES [kg]	Structure....... 4845 Power............ 5579 DPE................ 4857 Habitation....... 0 Misc............... 2499 Total.............. 17770*	Structure....... 6119 Power............ 11686 DPE................ 9714 Habitation....... 0 Misc............... 3852 Total.............. 31371*	Structure....... 5631 Power............ 5615 DPE................ 4857 Habitation....... 24402 Misc............... 4363 Total.............. 44868	Structure....... 5631 Power............ 5615 DPE................ 4857 Habitation....... 24402 Misc............... 4363 Total.............. 44868	Structure....... 6905 Power............ 11722 DPE................ 9714 Habitation....... 24402 Misc............... 5716 Total.............. 58559

* Mass statements for Options 1 & 2 which use SSF are only the Δ weight above that of SSF at assembly complete, necessary for LTV accommodations

GDSS-ISTD1-0105N

LTV ACCOMMODATION OPERATIONS SUMMARY
By Primary Resource Utilization

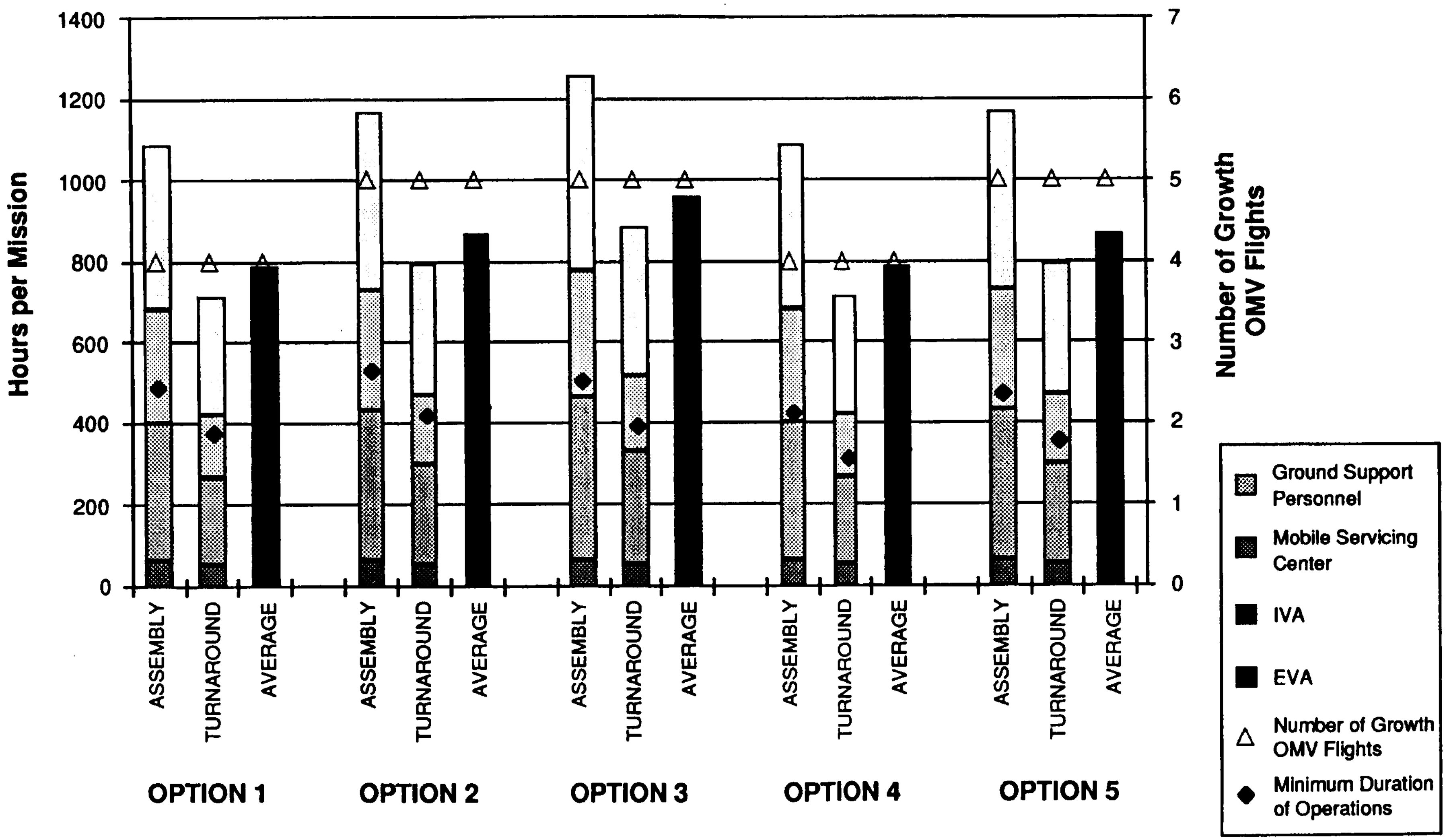
Operational scenarios and timelines for each of the five LTV accommodation options have been generated for comparison purposes. For each LTV scenario in the reusable mode, there is a single assembly and four turnaround missions for a total life of five missions. There are two primary operational sequences required. The first is for assembly of the LTV in preparation for its first of five missions. The second is for turnaround of the vehicle subsequent to its first flight. The average column on the chart below indicates the average of one assembly and four turnaround missions.

There are several resources used for on-orbit operations to support LTV missions, and the utilization of these resources has been identified in our analyses. The primary resources we identify include EVA, IVA, use of the mobile servicing center (MSC), and ground support personnel (GSP). The hours shown on this chart are the cumulative hours for each of these resources over the duration of the assembly or turnaround operations. EVA hours include the time for two EVA astronauts, and the GSP hours include the time for ten personnel.

The line showing minimum duration of operations is the sequential duration of the operations in terms of the estimated time the operations take. It is less than the hours per mission because some tasks take place in parallel. If one eight hour shift per day were assumed, then an operation with a minimum duration of 480 hours would take 60 working days to complete.

The triangles shown on the chart correspond with the axis on the right and indicate the number of growth OMV flights necessary to support the given operations.

LTV ACCOMMODATION OPERATIONS SUMMARY
By Primary Resource Utilization



Average hours are for a vehicle life of 5 missions: 1 assembly and 4 turnaround.

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LTV ACCOMMODATION OPERATIONS COSTS
By Primary Resource Utilization

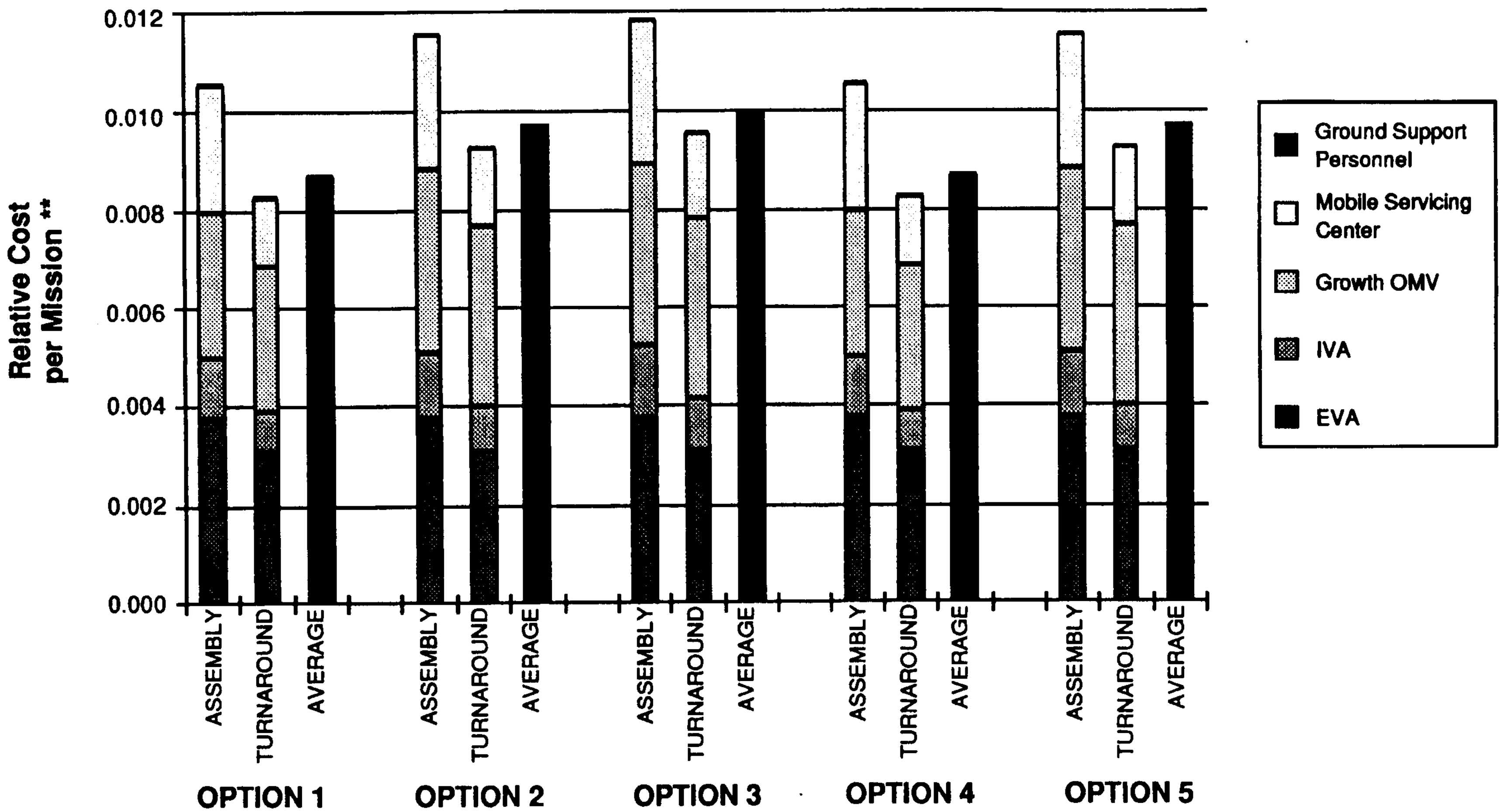
The hours identified in the previous chart have been multiplied by estimates of the costs of each of the respective resources to generate cost estimates of each of the LTV accommodation options.

EVA costs estimates per hour for two EVA astronauts have been applied for each hour shown on the previous chart. IVA costs estimate per hour for a single IVA astronaut have been similarly applied. Costs for each flight of the growth OMV have been included. The MSC costs estimates per hour have been included, as well as GSP costs per hour which include 10 personnel.

The costs shown on this chart are estimates for comparison purposes and do not include many other costs which would be associated with on-orbit accommodations for transfer vehicles. These costs are maintenance and repair of the facility, logistics resupply, and additional GSP which are necessary for regular operation and monitoring of on-orbit assets.

This analysis was intended to be comparative between the options being considered and not an estimate of the total actual costs associated with on-orbit operations.

LTV ACCOMMODATION OPERATIONS COSTS
By Primary Resource Utilization



* Average costs are for a vehicle life of 5 missions: 1 assembly and 4 turnaround.
** Relative costs are shown for comparison purposes only.

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LTV ACCOMMODATION OPTIONS EVALUATION

There are several criteria which should be used in the evaluation of alternative LTV accommodation options. These include the relative cost of the alternatives (DDT&E, production, and operations), the schedule and technical risk associated with each option, the complexity of operations, the impact to the LTV design of each option, the degree of on-orbit safety, and the impacts to SSF in terms of disturbances to on-going science activities as well as software hooks and hardware scars necessary for evolution and growth.

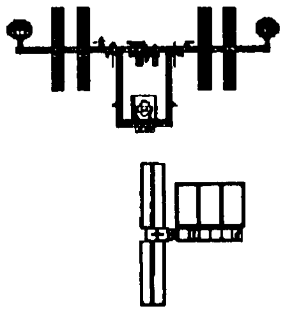
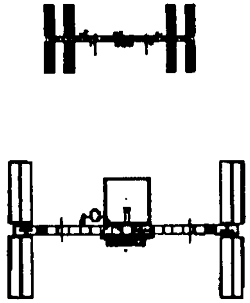
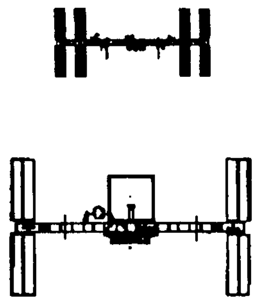
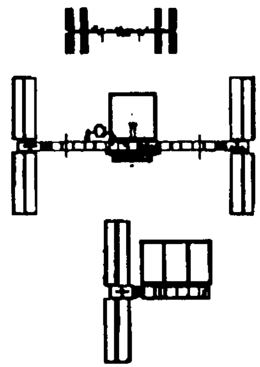
All relative cost estimates are in constant year dollars. The relative DDT&E and production costs include the NASA provided wraparound factors and the operations costs exclude the NASA provided wraparound factors.

Each of the options being considered has been evaluated against each of these criteria and assigned a relative ranking of high, medium, or low. The ***most*** favorable option(s) for each criteria has been highlighted. For all criteria, the low ranked options are most favorable.

Options 1, 3 & 4 are all good options which can meet the requirements and have good rankings for most of the criteria. The costs associated with DDT&E and production of Option 1 are somewhat higher than those of Options 3 & 4, and this is primarily because they include the development of solar dynamic power modules. The free-flying concepts were designed with low acquisition cost in mind and thus incorporated solar panels rather than solar dynamics. The major drawback of Option 1 is the relatively high impact it has on SSF, particularly on the scientific activities at the station. Additionally, if the IOC is moved prior to 2004 the schedule risks become severe for Option 1. The primary disadvantage of Options 3 & 4 are the additional schedule risks and operational considerations of multiple platforms in orbit.

Options 2 and 5 did not satisfy the evaluation criteria nearly as well as the other options and are not considered good options.

LTV ACCOMMODATION OPTIONS EVALUATION

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5
	ALL ACCOMMODATIONS AT SSF	ACCOMM AT SSF, WITH FREE FLYING PROP INTEG FACILITY	ACOMM AT MAN-TENDED FREE FLYING PLATFORM	ACCOMM AT PERM MANNED FREE FLYING PLATFORM	PERM MANN FF WITH FREE FLYING PROP INTEG FACILITY
CONFIG-URATIONS					
RELATIVE DDT&E COST**	*MED* 0.61*	HIGH 0.89*	LOW 0.52	LOW 0.52	HIGH 0.80
REL PRODUCTION COST**	LOW 0.22*	HIGH 0.39*	LOW 0.24	LOW 0.24	HIGH 0.41
RELATIVE LTV OPS COST**	LOW 0.17	MED 0.20	MED 0.20	LOW 0.17	MED 0.20
SCHED RISK (2004 IOC)	LOW Sufficient time for modifications	MED Additional platform development	MED Development of separate platform	MED Development of separate platform	MED Multiple platform developments
TECHNICAL RISK	LOW SSF h/w with new DPE & Sol Dyn	MED SSF common, but automated ops	LOW SSF common elements	LOW SSF common elements	MED SSF common, but automated ops
OPERATIONS COMPLEXITY	LOW All ops at SSF, with supervision	MED Tank integ requires automated ops	MED All ops at node, but man-tended	MED All ops at node, but multiple platforms	MED Tank integ requires automated ops
LTV DESIGN IMPACTS	LOW Impacts driven by assembly ops	MED Interface with multiple nodes	LOW Impacts driven by assembly ops	LOW Impacts driven by assembly ops	MED Interface with multiple nodes
SAFETY CONCERNS	MED All ops at SSF, some hazaradous	LOW Hazardous ops done off SSF	MED Hazardous ops, crew prox to SSF	MED All ops at node, some hazardous	LOW Hazardous ops done at tank integ
SSF IMPACTS/ Hooks & Scars	HIGH Hooks & Scars, and μ-G environ	HIGH Hooks & Scars, and μ-G environ	LOW Minimal impact on SSF - only crew	LOW No impact on SSF	LOW No impact on SSF
	Good Option		Good Option	Good Option	

* Options 1&2 costs include Solar Dynamics, which the other options do not.

** Cost estimates are preliminary and are relative values for comparison only. Ops Costs are at a flight rate of 1 per year over 20 years.

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LTV ASSEMBLY SEQUENCE (1 of 3)

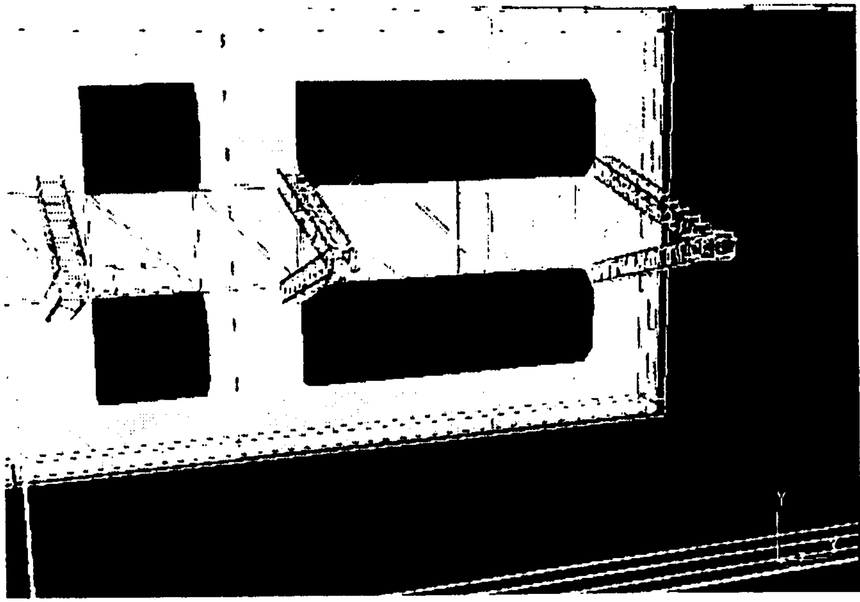
A computer model of SSF evolved to accommodate LTV operations was developed on GEOMOD to aid in visualizing and understanding the assembly operations and requirements. A model of the LTV was also developed, to be used with the accommodation concept.

The chart below is the first of three which identify the LTV assembly sequence inside the debris protection enclosure (DPE). The first four steps involved in the assembly buildup the aerobrake and the core module of the LTV.

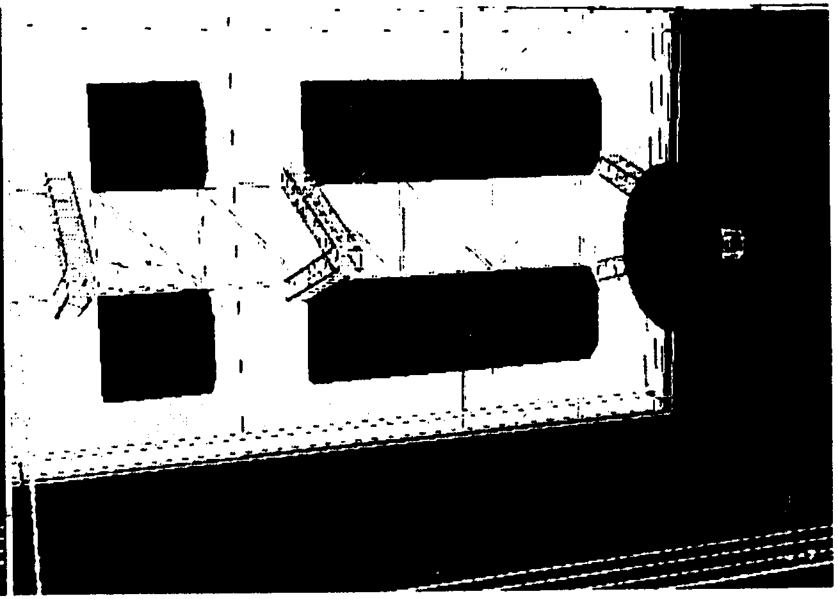
The first step shows the empty enclosure in a dormant mode prior to the delivery of any LTV components. The three raised trusswork elements are the LTV mounting and support fixtures. The fixtures on either end are fitted with a rotary berthing fixture (RBF) which provides the mechanical, electrical and fluid interfaces between the accommodation facility and the vehicle. The dark elements in the empty enclosure are the storage facilities for accommodation equipment and ORU's.

Step 2 shows the position of the core segment of the aerobrake as it is mounted with the RBF. The remainder of the aerobrake is shown mounted to the core aerobrake segment in Step 3. The P/A module and core structure of the LTV are shown mounted to the assembled aerobrake in Step 4 of the assembly process.

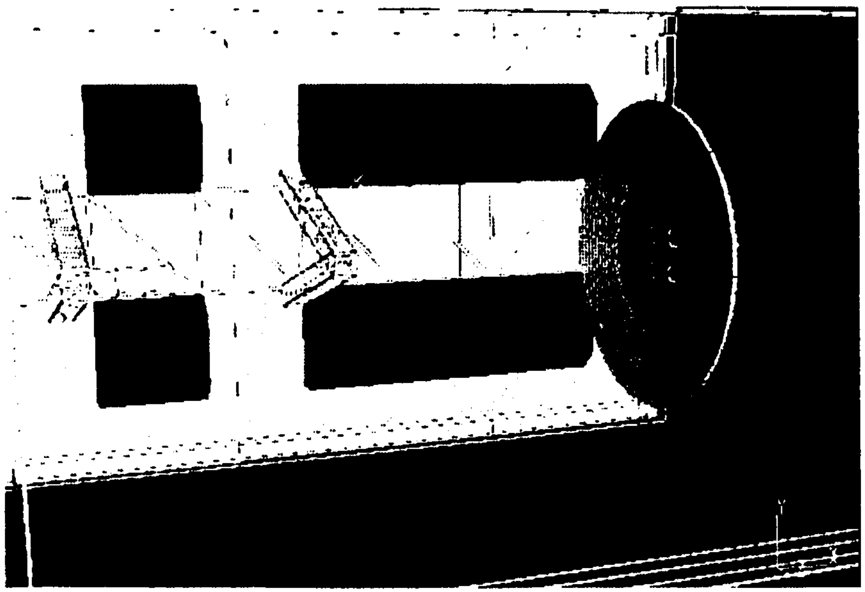
LTV ASSEMBLY SEQUENCE (1 of 3)



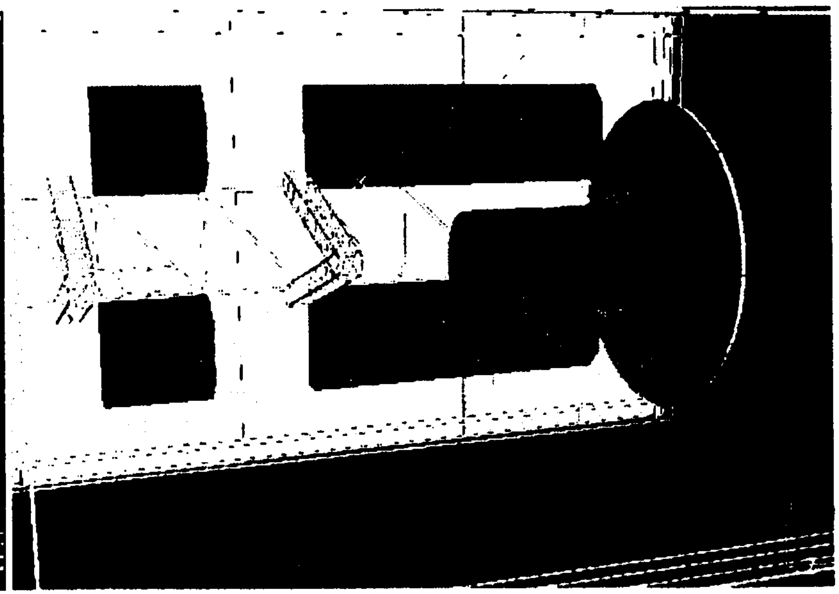
STEP 1: EMPTY ENCLOSURE



STEP 2: AEROBRAKE CORE



STEP 3: AEROBRAKE SEGMENTS



STEP 4: P/A MODULE & CORE STRUCTURE

GDSS-ISTD1-0129N

LTV ASSEMBLY SEQUENCE (2 of 3)

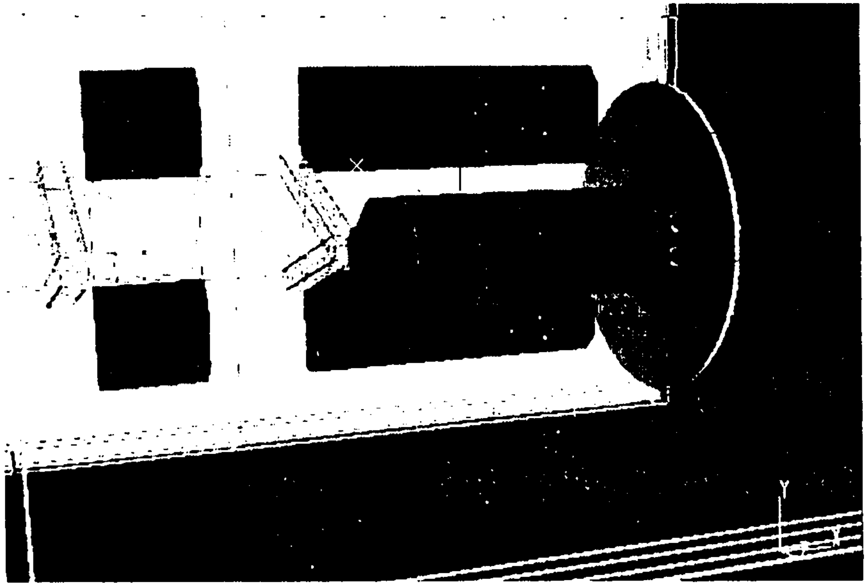
A computer model of SSF evolved to accommodate LTV operations was developed on GEOMOD to aid in visualizing and understanding the assembly operations and requirements. A model of the LTV was also developed, to be used with the accommodation concept.

The chart below is the second of three which identify the LTV assembly sequence inside the debris protection enclosure (DPE). This set of steps (5 through 8) identifies the integration of the crew modules and the LEV along with the payload that is to go to the moon.

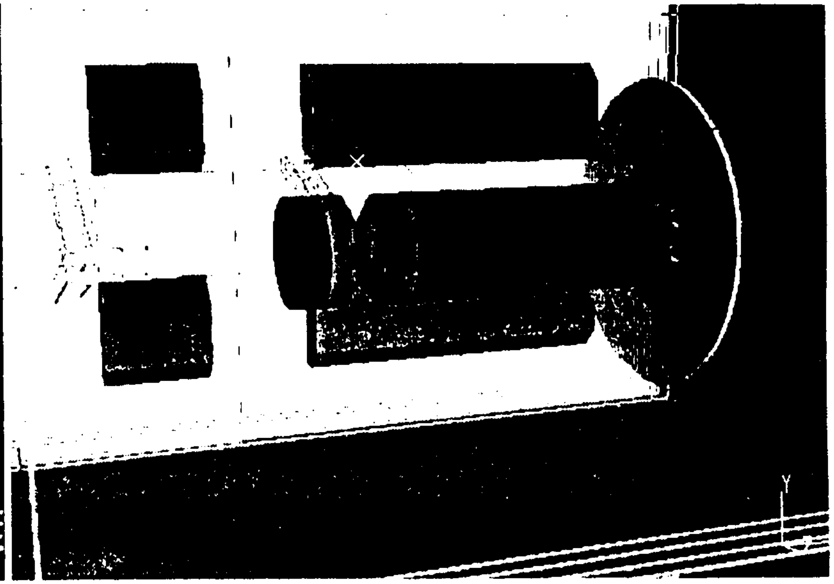
Step 5 of the assembly process integrates the LTV crew module with the core segment and aerobrake. The LTV crew module mounts to the center support in the DPE.

The LEV crew module is mated with the LTV crew module in Step 6, and the LEV is integrated with the rest of the LTV in Step 7. Payload to be delivered to the lunar surface by the LEV is integrated with that vehicle in Step 8 of the process.

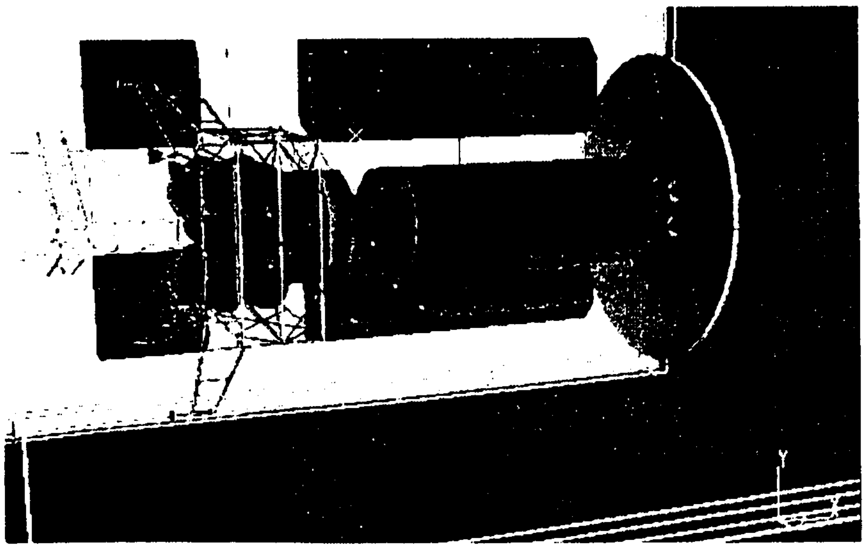
LTV ASSEMBLY SEQUENCE (2 of 3)



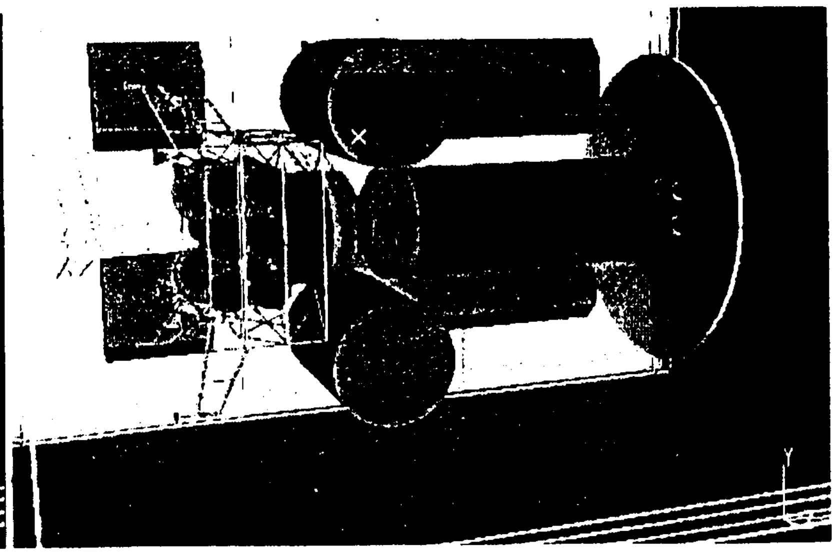
STEP 5: LTV CREW MODULE



STEP 6: LEV CREW MODULE



STEP 7: LEV INTEGRATION



STEP 8: LEV PAYLOAD INTEGRATION

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LTV ASSEMBLY SEQUENCE (3 of 3)

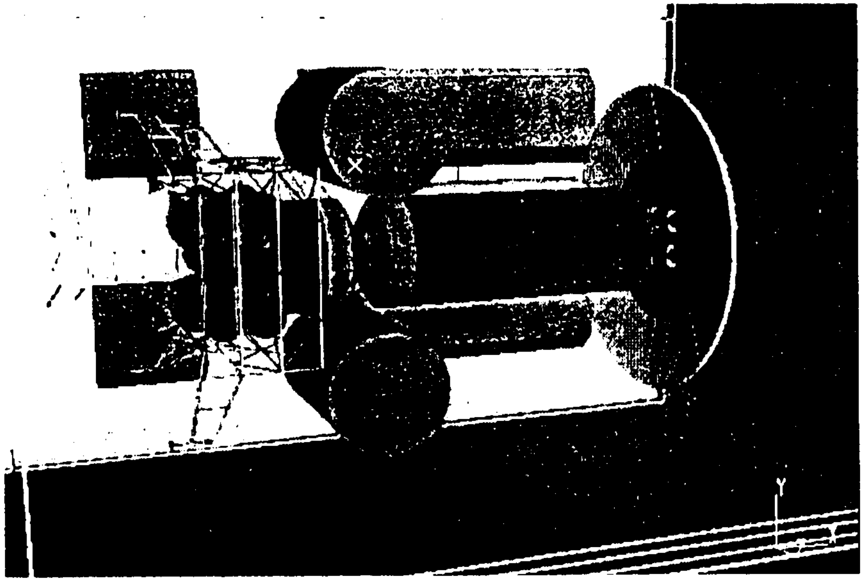
A computer model of SSF evolved to accommodate LTV operations was developed on GEOMOD to aid in visualizing and understanding the assembly operations and requirements. A model of the LTV was also developed, to be used with the accommodation concept.

The chart below is the third of three which identify the LTV assembly sequence inside the debris protection enclosure (DPE). This set of steps identifies the integration of the propellant tanks with the assembled LTV core and the LEV.

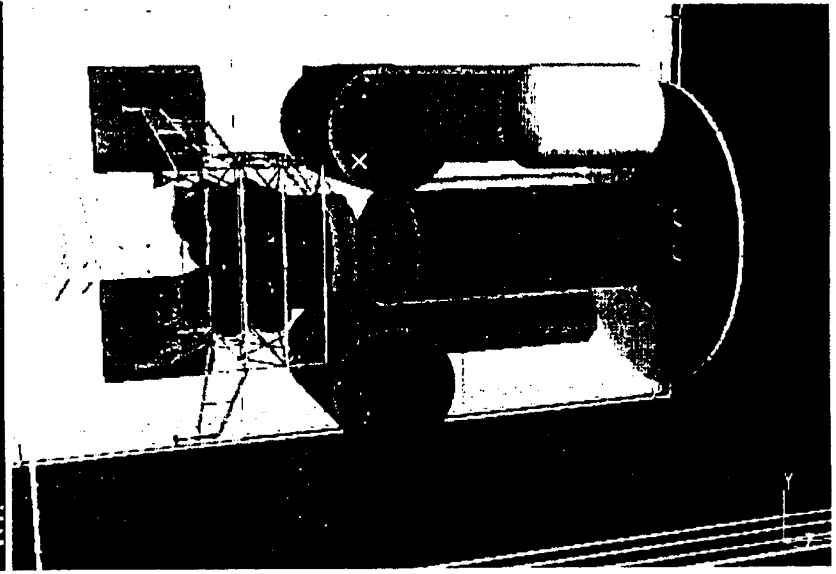
The first tank is integrated in Step 9. It is hidden behind the LTV core module and is only partially visible. There are two each of two different sized tanks to be integrated. The first tank is one of the large tanks.

The first small tank is integrated in Step 10, with the second large tank in Step 11 and the final tank in Step 12. This sequence completes the assembly of the LTV at the SSF based accommodation facility.

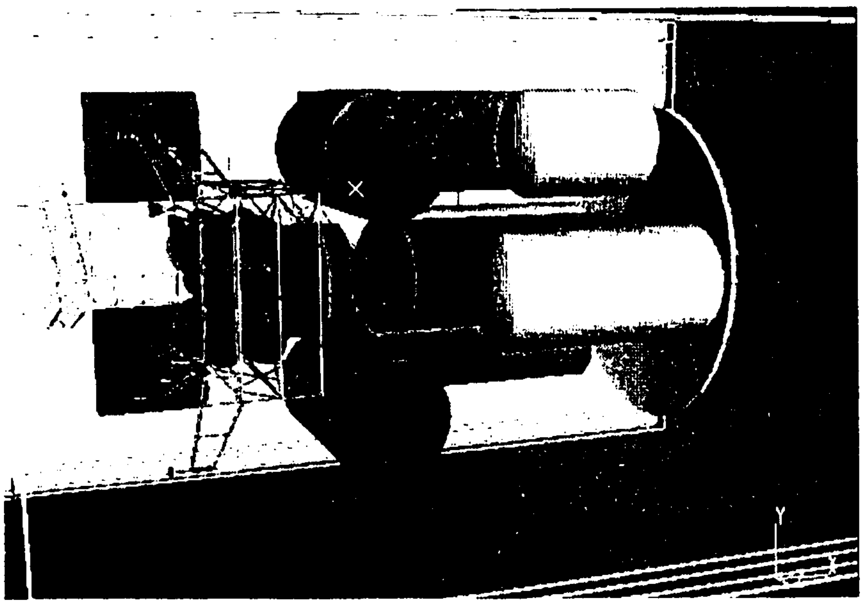
LTV ASSEMBLY SEQUENCE (3 of 3)



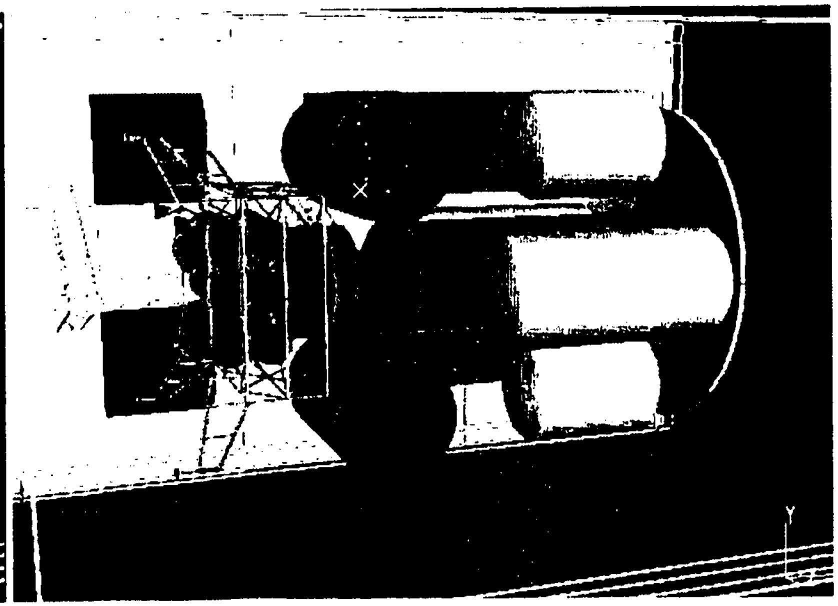
STEP 9: FIRST PROPELLANT TANK



STEP 10: SECOND PROPELLANT TANK



STEP 11: THIRD PROPELLANT TANK



STEP 12: FINAL PROPELLANT TANK

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LTV ACCOMMODATIONS TECHNOLOGY REQUIREMENTS

There are a number of technologies which must be developed to support on-orbit LTV accommodations. Included in these are thermal control, zero g vent and low g propellant mass gauging for the LTV propulsion system and tanks. Automated fault detection/isolation and system checkout is an avionics technology requirement.

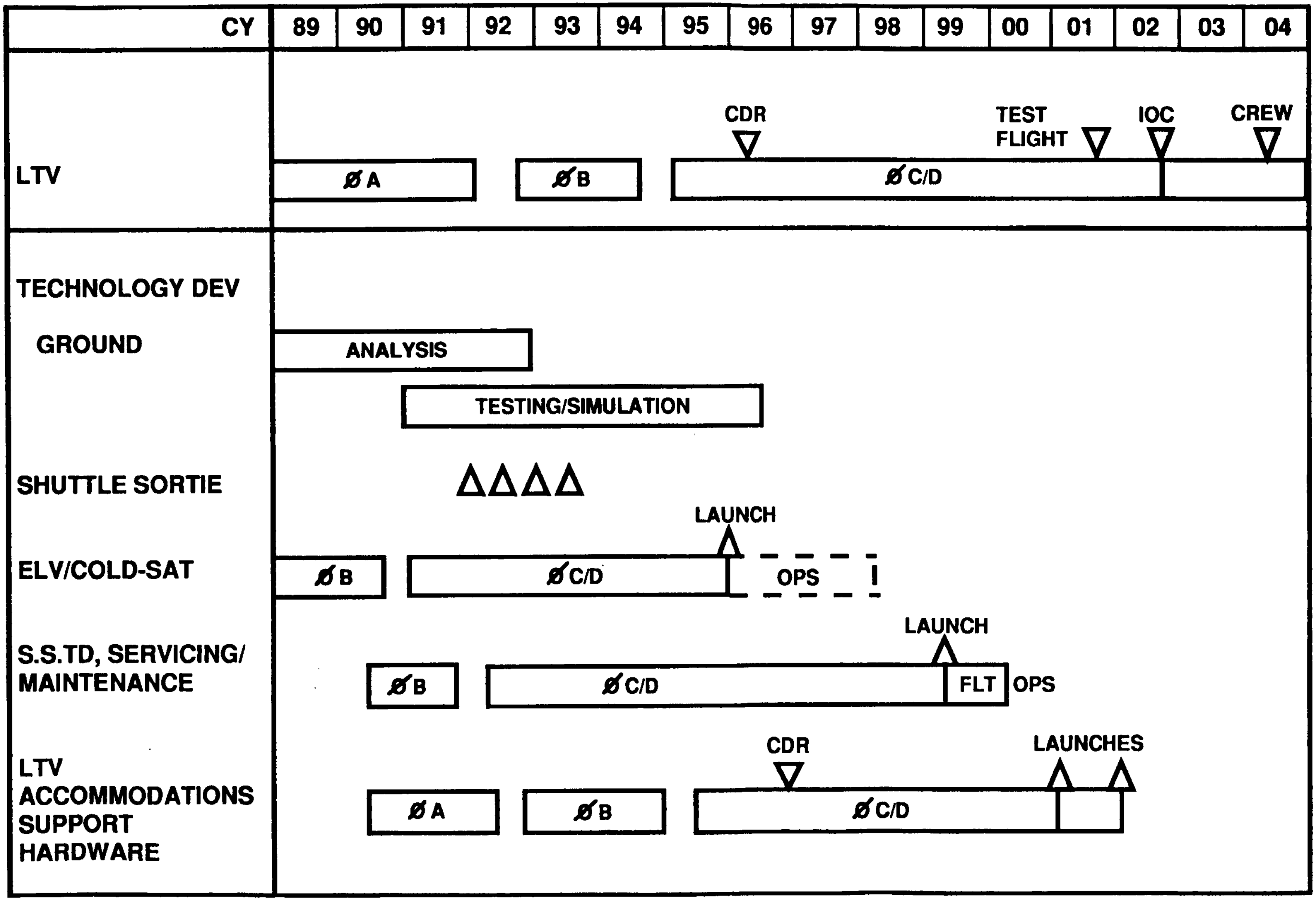
There are several technologies in the structure, materials and manufacturing area that must be developed including multi-use cryogenic vehicles, automated fluid and electrical disconnects, and reusable cryogenic tankage.

Ground and flight operations require the most technology development, particularly in the area of maintenance/servicing operations for the LTV and facilities/support equipment. Technologies in this area include teleoperation/robotics, crew translation equipment, LTV translating, berthing, & rotation equipment, controls and displays, EVA operations, visual inspection and leak check and detection, data management, and facility checkout and operations provisions. Also necessary are technologies for providing payload mating/interfaces for the LTV/LEV and lunar payload, and a automated docking and berthing technologies.

Technology demonstration missions for these technologies should be performed at the Space Station in the 1999 time period to influence the accommodations design in a timely manner. To meet an IOC earlier than 2004, the station will be unavailable for technology demonstration missions.

To support an IOC of 2004 for the man-rated aerobraked LTV, Phase A studies for the LTV accommodations support hardware should begin in 1990. Phase B studies for a space station technology demonstration on servicing and maintenance should begin in 1990 as well.

LTV ACCOMMODATIONS TECHNOLOGY REQUIREMENTS



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TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
Outline

- INTRODUCTION
- REQUIREMENTS
- LUNAR TRANSFER VEHICLE ACCOMMODATIONS
- MARS TRANSFER VEHICLE ACCOMMODATIONS
- CONCLUSIONS

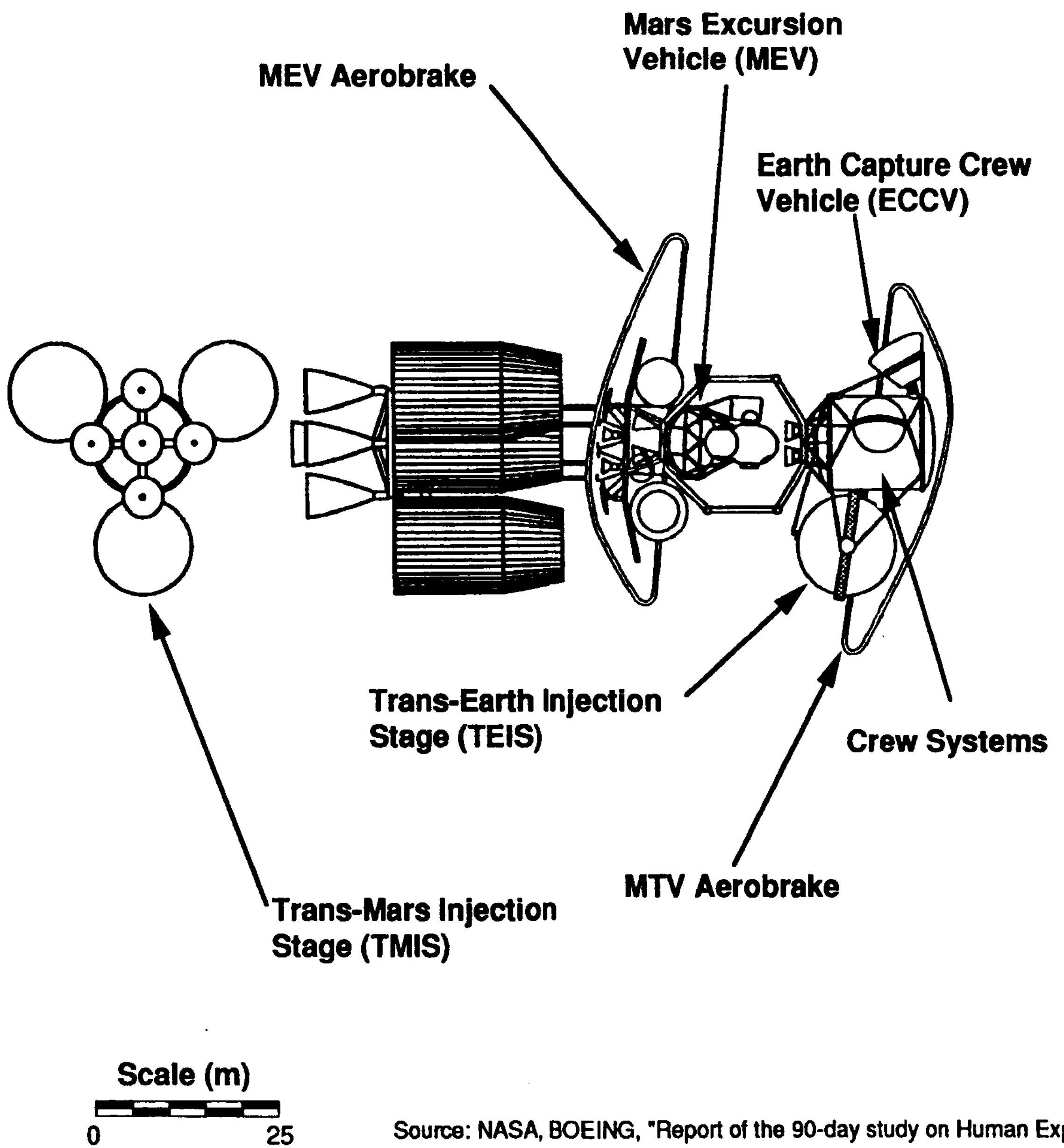
MARS TRANSFER VEHICLE
Vehicle Definition

The Mars Transfer Vehicle (MTV) used during this analysis appears below. This 3 component system is all cryogenic and utilizes aerobrakes at both Mars and Earth.

The Mars Excursion Vehicle (MEV) includes a 20m x 30m aerobrake with a 15.5m high ascent/descent stage. The MTV has a similar sized aerobrake with a 15.7m high stage.

The Trans-Mars Injection Stage (TMIS) is 23.7m in length with 4 clustered 8.2m dia tanksets. Mass properties for these components are shown below.

MARS TRANSFER VEHICLE
Vehicle Description



TYPICAL DELIVERY SEQUENCE:
7 Launches (HLLV)

1) Crew Systems, MTV A/B, Equip.
2) TEIS, Ascent Stage, Payload
3) MEV A/B, Descent Stage
4) TMI Stage with Engines

5-7) TMI Stages (1 each)

MTV MASS PROPERTIES SUMMARY (t)

MEV....................71.6
- Crew Module..........3.9
- Ascent Stage..........19.2
- Descent Stage........15.2
- Aerobrake...............8.3
- MEV Payload..........25.0

MTV....................702.7
- Crew Module..........33.2
- TEIS.........................100.7
- Aerobrake...............28.6
- ECCV........................7.5
- Misc "P/L"................10.0
- TMIS / Interstage....522.7

TOTAL................774.3

Source: NASA, BOEING, "Report of the 90-day study on Human Exploration of the Moon and Mars", November 1989

GDSS-ISTD1-0106N

TYPICAL MARS MISSION SCENARIO
Transportation Node / Infrastructure Element Interfaces

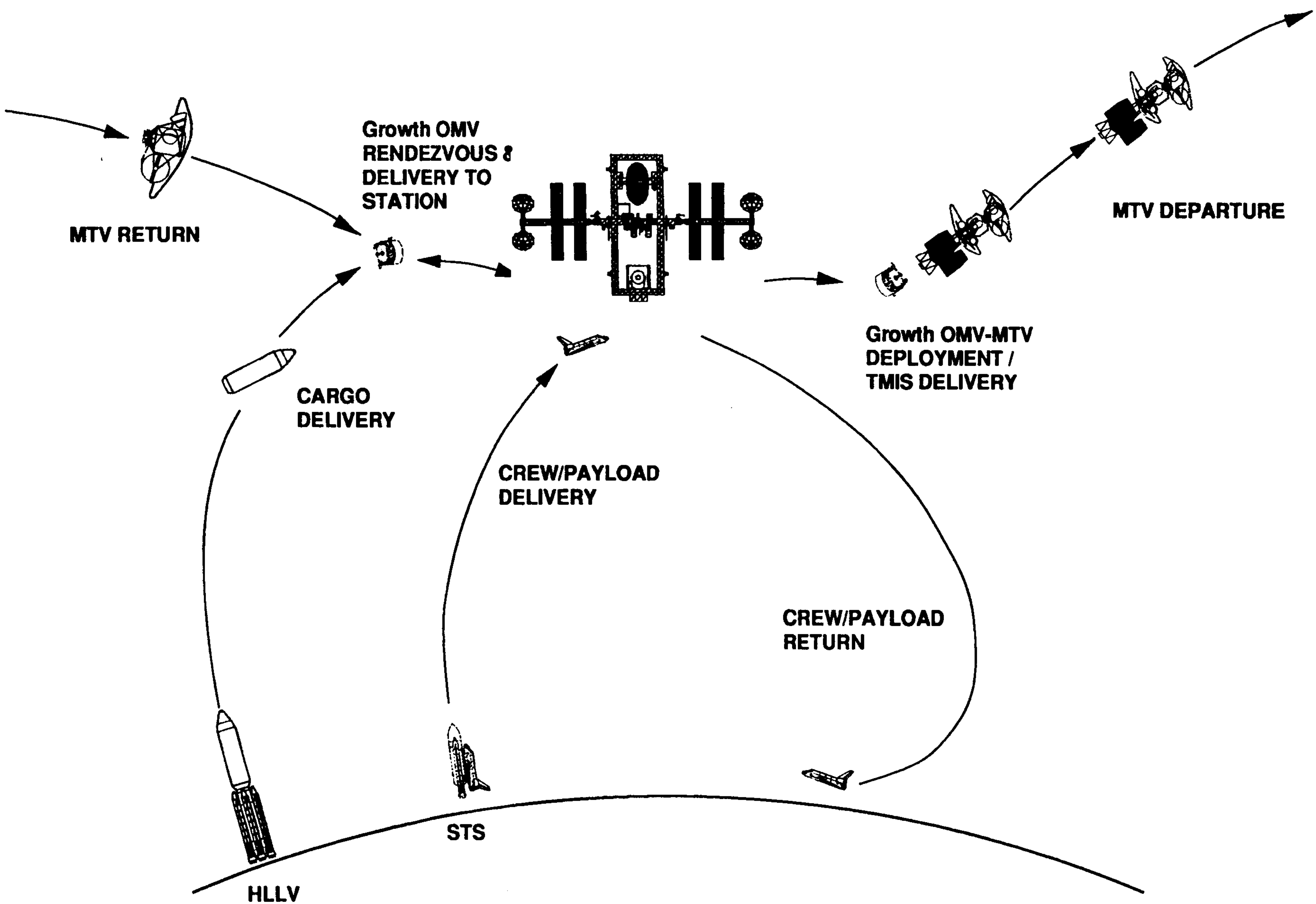
There are several infrastructure elements which must interface with the transportation node in support of a typical Mars mission scenario. These elements include ETO cargo vehicles and crew delivery vehicles, vehicles to provide transportation between cargo vehicles or returning spacecraft and the node, and the interface with the MTV for assembly, integration, and maintenance.

ETO cargo vehicles can have a significant impact on the operations at the transportation node. This is a function of the lift capability and the geometric cargo envelope of the vehicle. These factors affect the amount of vehicle assembly that must be done due to element sizing, and the number of elements, particularly propellant tanks that must be delivered and integrated on-orbit. An ETO vehicle being considered is the shuttle-derived HLLV, with an ETO lift capability of 140t.

The transfer of cargo between the ETO vehicle and the node is performed by a growth version of the orbital maneuvering vehicle (OMV). The capabilities of the growth OMV are determined by the lift capability of the ETO vehicle, and the size of the cargo it delivers. For the defined cargo vehicle, the growth OMV must have the capability to transfer a 140t payload.

Crew delivery and return is performed by the STS.

TYPICAL MARS MISSION SCENARIO
Transportation Node / Infrastructure Element Interfaces



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MTV ACCOMMODATION OPTIONS

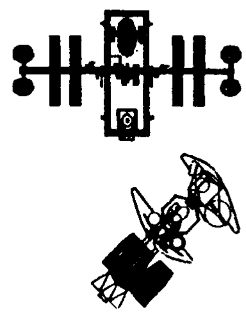
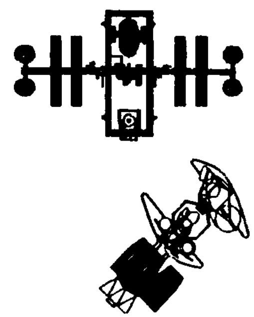
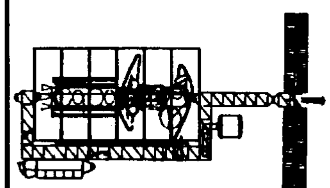
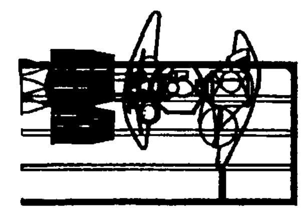
Five primary transportation node concepts have been identified for Mars Transfer Vehicle (MTV) accommodations. These configurations range from those utilizing an evolved SSF to a separate node supporting autonoumous vehicle assembly.

Options one through three are based on evolving the current SSF into a transportation node. These three options are similiar with the variable being the degree of operational impacts involved in transfering MTV components off of SSF for differerent degrees of off-station vehicle integration.

Option 4 portrays a free flying , man-tended platform at which vehicle components are assembled and integrated. The MTV is attached to two rotary joints at either end. These rotate allowing the robotic arm easy access circumferentially around the vehicle and along the strongback. There are no operational impacts to the SSF with this option.

In option five, the MTV autonomously assembles itself while being protected by a free flying debris protection enclosure (DPE).

MTV ACCOMMODATION OPTIONS

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5
	AEROBRAKE, MTV,MEV ASSEMBLED & MATED AT SSF	AEROBRAKE, MTV,MEV ASSEMBLED AT SSF, MATED OFF SSF	AEROBRAKE ASSEMBLY AT SSF, MATING OFF SSF	NEW FREE-FLYING NODE	AUTONOMOUS VEHICLE ASSEMBLY AT MTV NODE
CONFIGURATION					
DESCRIPTION	All MTV assembly is done at SSF, with TMIS integ done off the station. An upper keel, debris protection enclosure (DPE), add'l hab module and add'l power modules are the primary additions to the LTV accom station.	Option 2 utilizes similar SSF additions as option 1. Major components of the MTV are assembled at SSF and integrated off the station. TMIS stages are also integrated off the station.	MTV aerobrake assembly is done at SSF which has similar additions to Option 1. After assembly, the aerobrake acts as an integration platform and SSF is not used for the completion of the assembly and integration.	A free-flying transp node is used for Option 4. All on-orbit assembly and integration is done at the free-flyer. Hardware for the free-flyer is SSF derived. The MTV crew module houses the assembly crew.	Autonomous vehicle assembly is maximized for Option 5. A debris protection enclosure is provided, and the MTV uses on-board systems to perform assembly and integration.
MASS PROPERTIES [kg]	Structure....... 5,800 Power............ 5,579 DPE................ 26,104 Habitation....... 24,402 Misc............... 8,377 Total.............. 70,262*	Structure....... 5,800 Power............ 5,579 DPE................ 26,104 Habitation....... 24,402 Misc............... 8,377 Total.............. 70,262*	Structure....... 5,800 Power............ 5,579 DPE................ 26,104 Habitation....... 24,402 Misc............... 8,377 Total.............. 70,262*	Structure....... 5,574 Power............ 5,616 DPE................ 26,104 Habitation....... 33,983 Misc............... 6,922 Total.............. 78,199	Structure....... 1,026 Power............ 3,297 DPE................ 26,104 Habitation....... 0 Misc............... 4091 Total.............. 34,518

* Mass statements for Options 1,2 & 3 which use SSF are only the Δ weight above that for SSF Lunar accommodations, necessary for MTV accommodations

GDSS-ISTD1-0110N

MTV ACCOMMODATION OPERATIONS SUMMARY
By Primary Resource Utilization

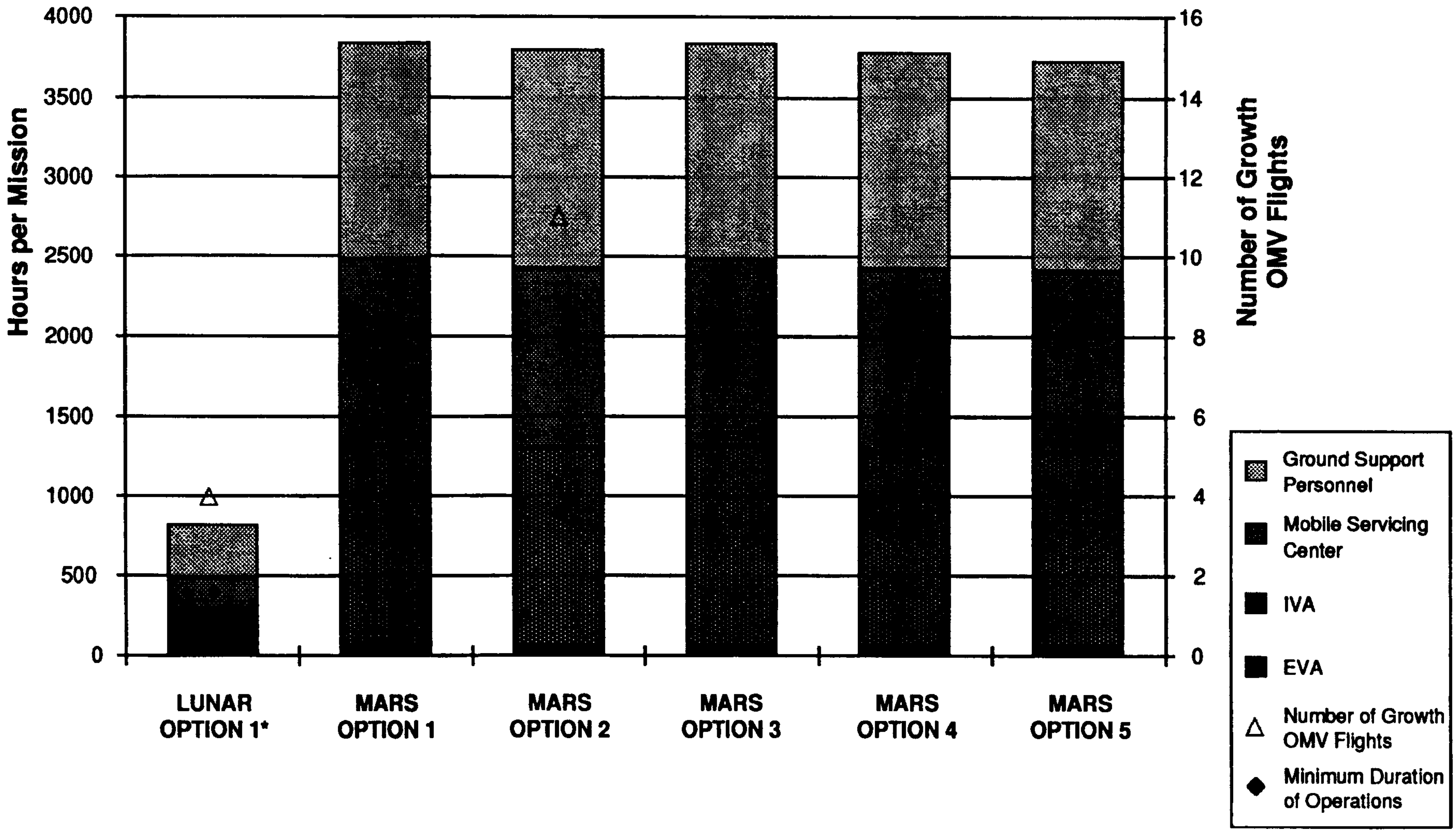
Operational scenarios and timelines for each of the five MTV accommodation options have been generated to develop a sense of the differences between the options.

There are several resources used for on-orbit operations necessary to support MTV missions, and the utilization of these resources has been identified in our analyses. The primary resources we identify include EVA, IVA, use of the mobile servicing center (MSC), and ground support personnel (GSP). The hours shown on this chart are the cumulative hours for each of these resources over the duration of the assembly or turnaround operations. EVA hours include the time for two EVA astronauts, and the GSP hours include the time for ten personnel.

The line showing minimum duration of operations is the sequential duration of the operations in terms of the estimated time the operations take. If one eight hour shift per day were assumed, then an operation with a minimum duration of 480 hours would take 60 working days to complete. These values are lower than the total hours per mission due to parallel operations.

The triangles shown on the chart correspond with the axes on the right and indicate the number of growth OMV flights necessary to support the given operations. There is a significant difference in number of growth OMV flights for the five options, ranging from 11 for Option 2 to only 7 for Option 5.

MTV ACCOMMODATION OPERATIONS SUMMARY
By Primary Resource Utilization



*Lunar Option 1 average (Accommodations at SSF) is shown for comparison purposes

GDSS-ISTD1-0116N

MTV ACCOMMODATION OPERATIONS COSTS
By Primary Resource Utilization

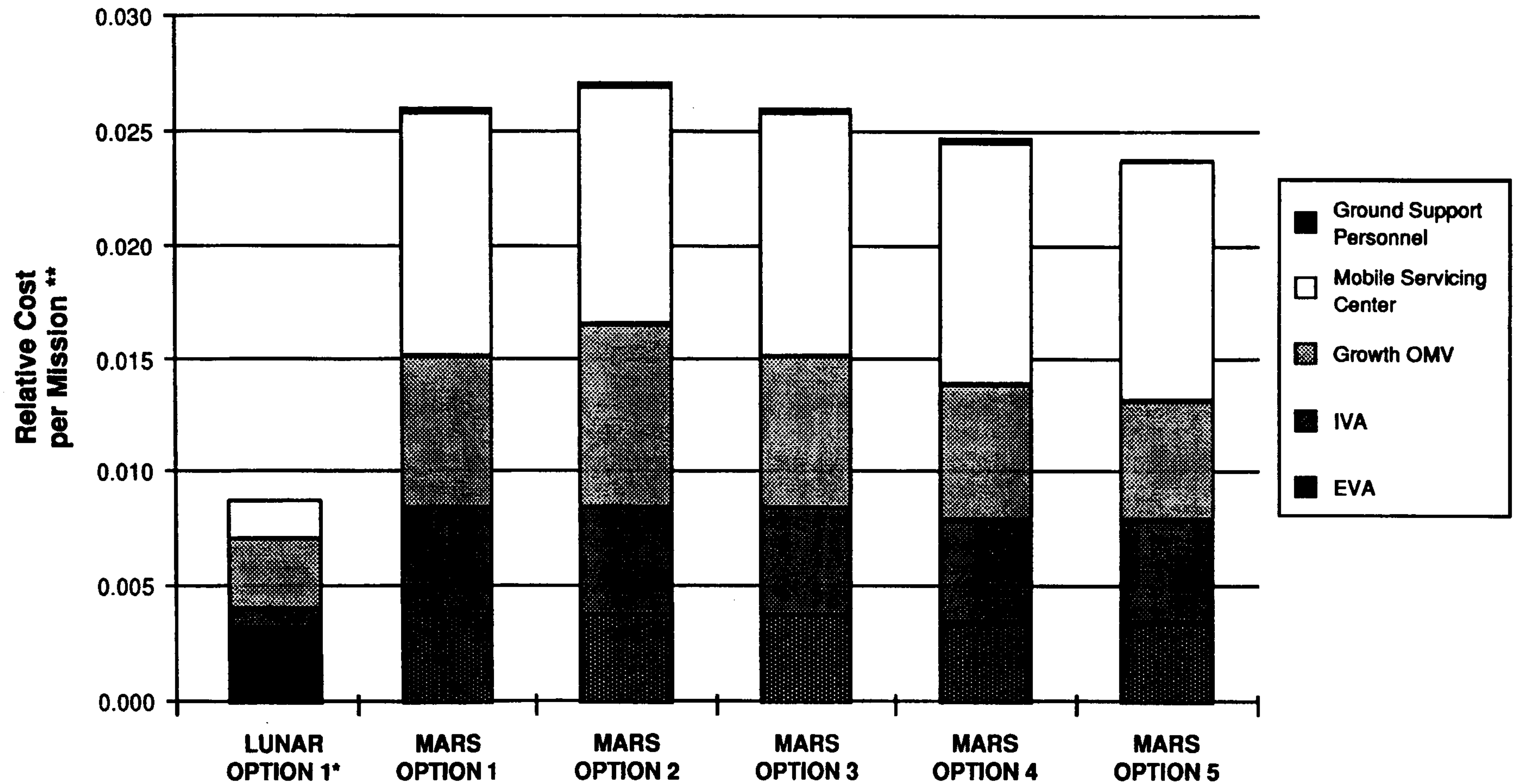
The hours identified in the previous chart have been multiplied by estimates of the costs of each of the respective resources to generate cost estimates of each of the MTV accommodation options.

EVA costs estimates per hour for two EVA astronauts have been applied for each hour shown on the previous chart. IVA costs estimate per hour for a single IVA astronaut have been similarly applied. Costs for each flight of the growth OMV have been included. The MSC costs estimates per hour have been included, as well as GSP costs per hour which include 10 personnel.

The costs shown on this chart are estimates for comparison purposes and do not include many other costs which would be associated with on-orbit accommodations for transfer vehicles. These costs are maintenance and repair of the facility, logistics resupply, and additional GSP which are necessary for regular operation and monitoring of on-orbit assets.

This analysis was intended to be comparative between the options being considered and not an estimate of the total actual costs associated with on-orbit operations.

MTV ACCOMMODATION OPERATIONS COSTS
By Primary Resource Utilization



* Lunar Option 1 average cost (Accommodations at SSF) is shown for comparison purposes
** Relative costs are shown for comparison purposes only.

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MTV ACCOMMODATION OPTIONS EVALUATION

There are several criteria which should be used in the evaluation of alternative MTV accommodation options. These include the relative cost of the alternatives (DDT&E, production, and operations), the schedule and technical risk associated with each option, the complexity of operations, the impact to the MTV design of each option, the degree of on-orbit safety, and the impacts to SSF in terms of disturbances to on-going science and LTV accommodation activities as well as software hooks and hardware scars necessary for evolution and growth.

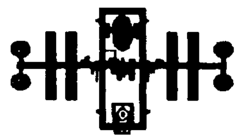
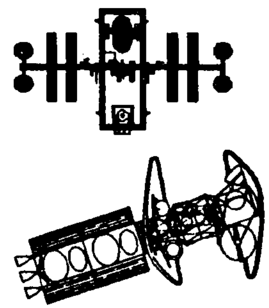
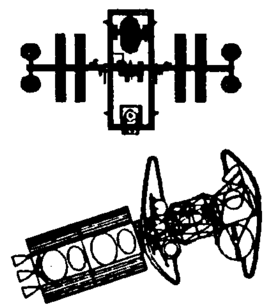
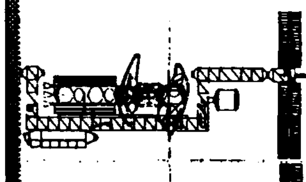
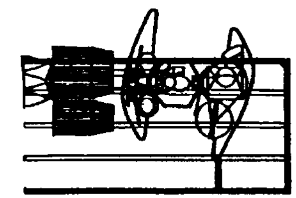
All relative cost estimates are in constant year dollars. The relative DDT&E and production costs include the NASA provided wraparound factors and the operations cost exclude the NASA provided wraparound factors.

Each of the options being considered has been evaluated against each of these criteria and assigned a relative ranking of high, medium, or low. The ***most*** favorable option(s) for each criteria has been highlighted. For all criteria but on-orbit safety, the low ranked options are most favorable.

Option 4, which places the accommodations at a new free-flying transportation node is the preferred option of the five. This option is somewhat higher in DDT&E cost than the other options, but has other advantages which offset this including low operations costs. This option is most favorable in terms of schedule and technical risk, because it has limited technical development, incorporates many SSF developed hardware items, and is allowed ample development time. The operational complexity of Option 4 is relatively low, with all operations occurring at the node and a minimum of transfer of payloads between different platforms or locations. The impact which this option will have on the MTV design is relatively low, and it will have no impacts on SSF.

Using SSF for accommodating the MTV to a lesser degree is feasible, but there would be a high degree of impact on the SSF in terms of scientific disruption as well as software hooks and hardware scars. The autonomous vehicle assembly of Option 5 is somewhat risky from a technical and schedule standpoint. This is because of the added complexity placed on the MTV for performing these tasks in an autonomous mode.

MTV ACCOMMODATION OPTIONS EVALUATION

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5
CONFIG-URATIONS	AEROBRAKE, MTV,MEV ASSEMBLED & MATED AT SSF	AEROBRAKE, MTV,MEV ASSEMBLED AT SSF, MATED OFF SSF	AEROBRAKE ASSEMBLY AT SSF, MATING OFF SSF	NEW FREE-FLYING NODE	AUTONOMOUS VEHICLE ASSEMBLY AT MTV NODE
					
RELATIVE DDT&E COST**	MED 0.61*	MED 0.61*	MED 0.61*	MED 0.61	LOW 0.37
REL PRODUCT-ION COST**	MED 0.30*	MED 0.30*	MED 0.30*	MED 0.33	LOW 0.17
REL MTV OPS COST **	LOW 0.26	LOW 0.28	LOW 0.26	LOW 0.24	LOW 0.24
SCHED RISK (2013 IOC)	LOW Long lead time, Mod tech devel	LOW Long lead time, Mod tech devel	MED Long lead, but some Adv Tech	LOW Long lead time, Mod tech devel	MED Long lead, but some Adv Tech
TECHNICAL RISK	LOW SSF h/w with new DPE	MED SSF common, some autoops	MED SSF common, adv automated ops	LOW SSF common elements	MED SSF common, adv automated ops
OPERATIONS COMPLEXITY	LOW All ops at SSF, with supervision	MED Ass'y at SSF, Integ off station	HIGH Most off station, adv automated ops	LOW All ops at node, with supervision	HIGH Requires advanced automated ops
MTV DESIGN IMPACTS	LOW Impacts driven by assembly ops	MED Must allow auto integration ops	HIGH A/B impacts and automated ops	LOW Impacts driven by assembly ops	HIGH Built in cap for auto ass'y & integration
SAFETY CONCERNS	LOW TMIS integration off station	LOW TMIS & vehicle integ off station	LOW TMIS & vehicle integ off station	MED All ops at node, some hazardous	MED All ops at node, some hazardous
SSF IMPACTS/ Hooks & Scars	HIGH Hooks & Scars, and μ-G environ	HIGH Hooks & Scars, and μ-G environ	MED Hooks & Scars, and μ-G environ	LOW No impact on SSF	LOW No impact on SSF
				Preferred Option	

* Option 1-3 costs include Solar Dynamics, which options 4&5 do not.
** Cost estimates are preliminary and for comparison only in constant year dollars. Ops Costs are for 10 flights over 20 years.

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MTV ASSEMBLY SEQUENCE (1 of 2)

A computer model of the free-flying transportation node designed to accommodate the MTV was developed on GEOMOD to aid in visualizing and understanding the assembly and integration operations and requirements. A model of the MTV was also developed, to be used with the accommodation concept.

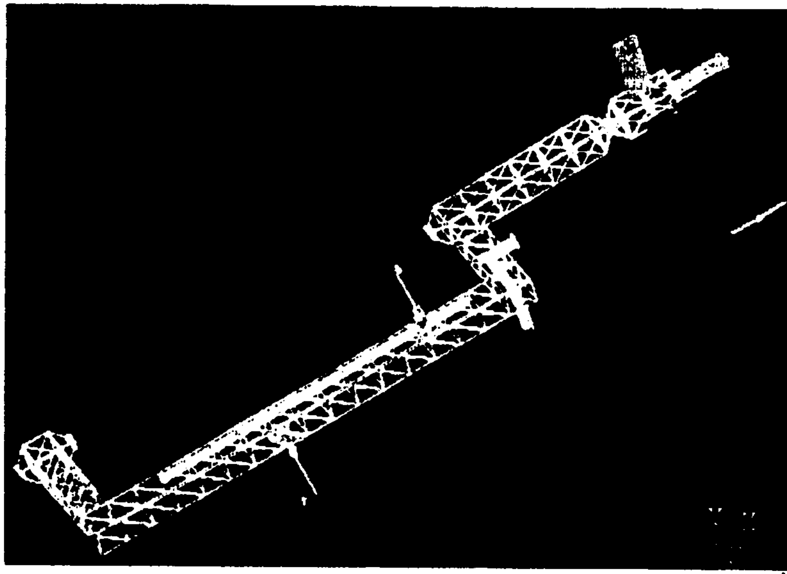
The chart below is the first of two which identify the MTV assembly sequence at the transportation node. For clarity the debris protection enclosure (DPE) is not shown. The first four steps are delivery and integration of the crew module with the node, and buildup of the MTV and MEV aerobrakes.

The first step shows the node in a dormant mode prior to the delivery of any MTV components. The fixtures on either end are fitted with a rotary berthing fixture (RBF) which provides the mechanical, electrical and fluid interfaces between the accommodation facility and the vehicle. The section of truss members opposite the power module on the node is a moveable support which adjusts to the degree to which the MTV is assembled.

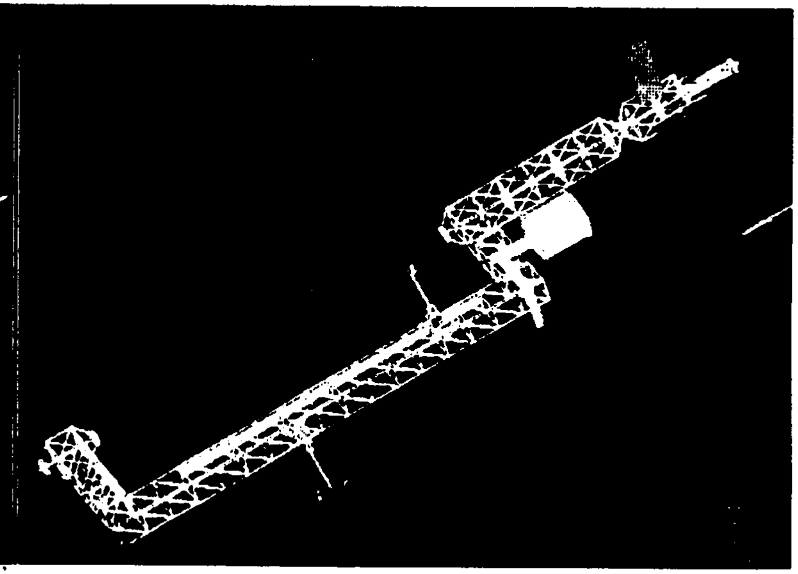
Step 2 indicates shows the crew module integrated into its position on the node for the assembly process. The crew module houses the assembly crew during the assembly, and is connected by pressurized tunnel, to an STS docking fixture. Once assembly is complete, the crew module is integrated with the assembled MTV.

The MTV aerobrake is assembled in Step 3 and integrated with the trans-Earth injection stage (TEIS). The MEV and its aerobrake are assembled and integrated with the MTV aerobrake in Step 4 of the assembly sequence.

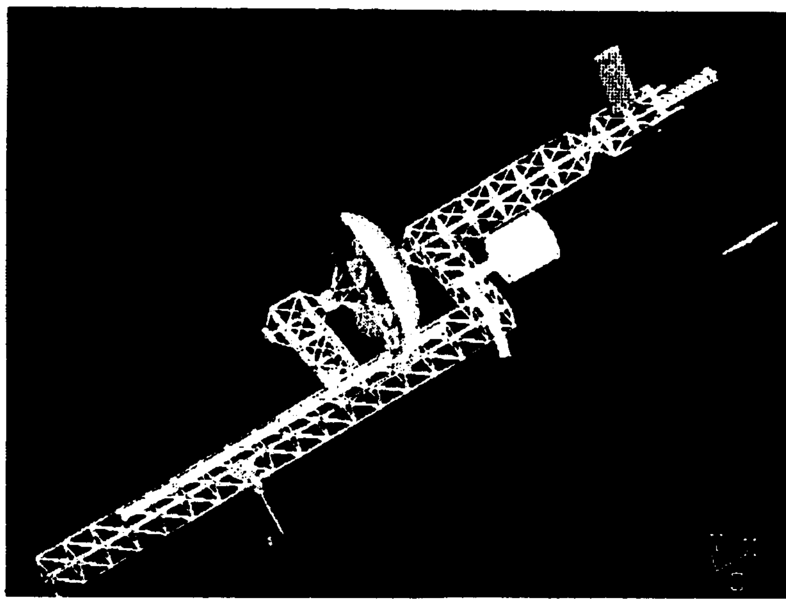
MTV ASSEMBLY SEQUENCE (1 of 2)



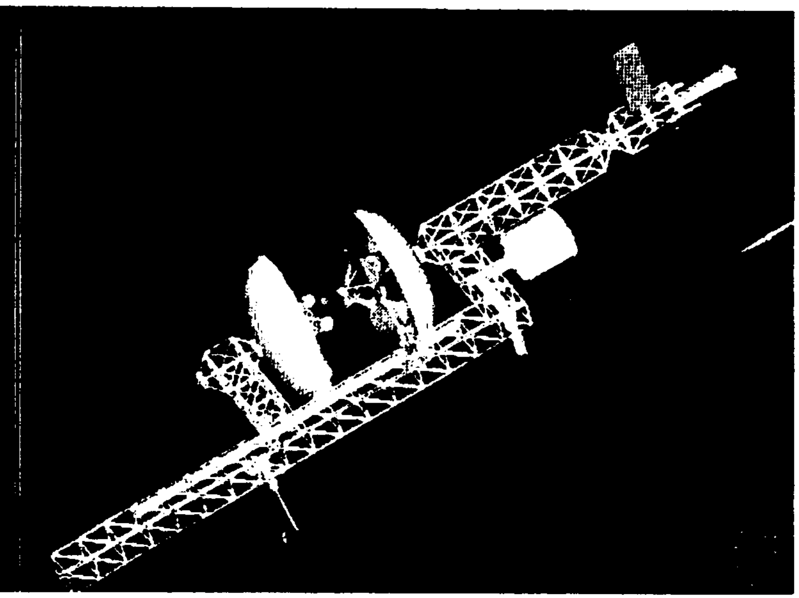
STEP 1: DORMANT NODE



STEP 2: CREW MODULE INTEGRATION



STEP 3: MTV AEROBRAKE ASSEMBLY



STEP 4: MEV & MEV AEROBRAKE ASSEMBLY

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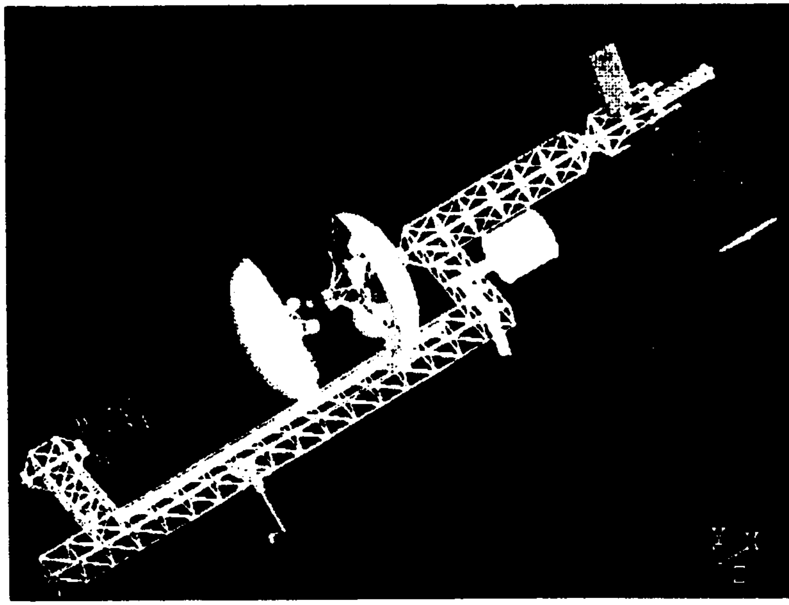
MTV ASSEMBLY SEQUENCE (2 of 2)

A computer model of the free-flying transportation node designed to accommodate the MTV was developed on GEOMOD to aid in visualizing and understanding the assembly and integration operations and requirements. A model of the MTV was also developed, to be used with the accommodation concept.

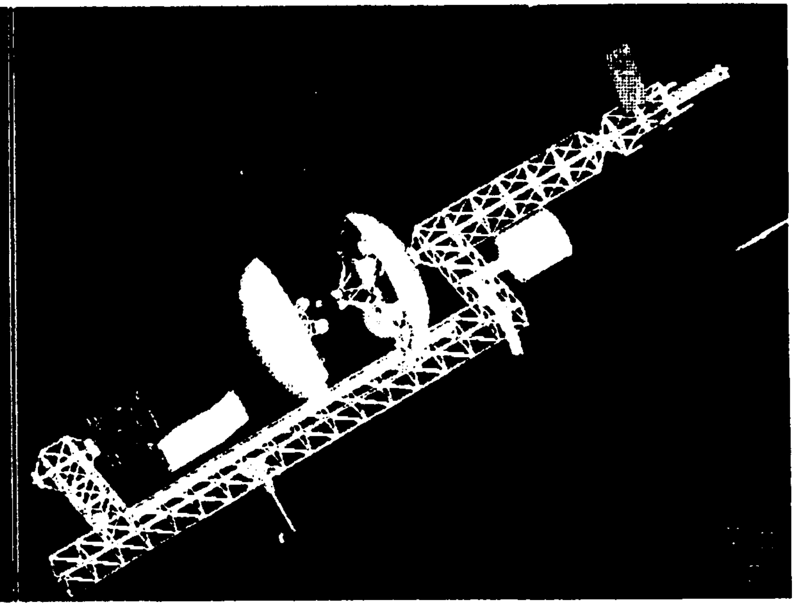
The chart below is the second of two which identify the MTV assembly sequence at the transportation node. For clarity the debris protection enclosure (DPE) is not shown. The final steps shown below are integration of the four trans-Mars injection stages (TMIS).

The first TMIS tank is delivered and integrated in step 5. This TMIS tank includes the TMIS propulsion system while the remaining three are only propellant. Steps 6, 7, and 8 integrate the remaining three TMIS tanks, with the crew module being integrated with the rest of the MTV in Step 8.

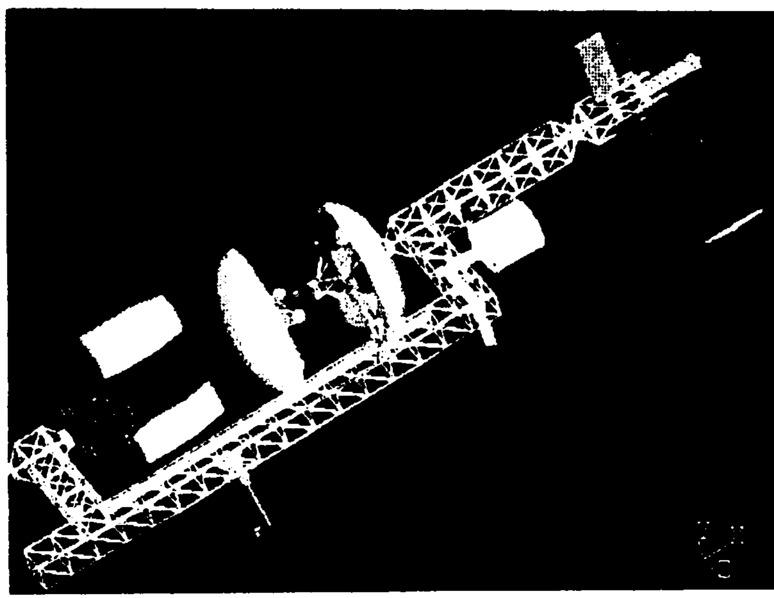
MTV ASSEMBLY SEQUENCE (2 of 2)



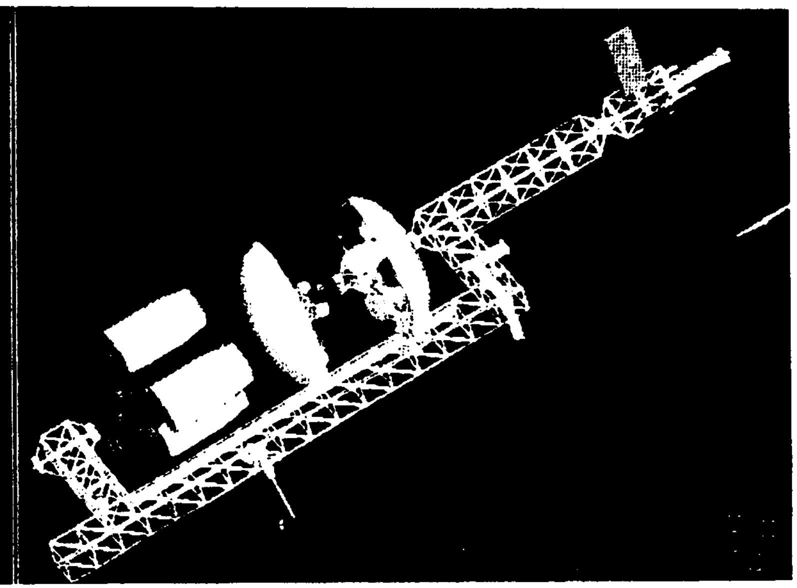
STEP 5: FIRST TMIS TANK INTEGRATION



STEP 6: SECOND TMIS TANK INTEGRATION



STEP 7: THIRD TMIS TANK INTEGRATION



STEP 8: FINAL TMIS TANK INTEGRATION

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MTV ACCOMMODATIONS TECHNOLOGY REQUIREMENTS

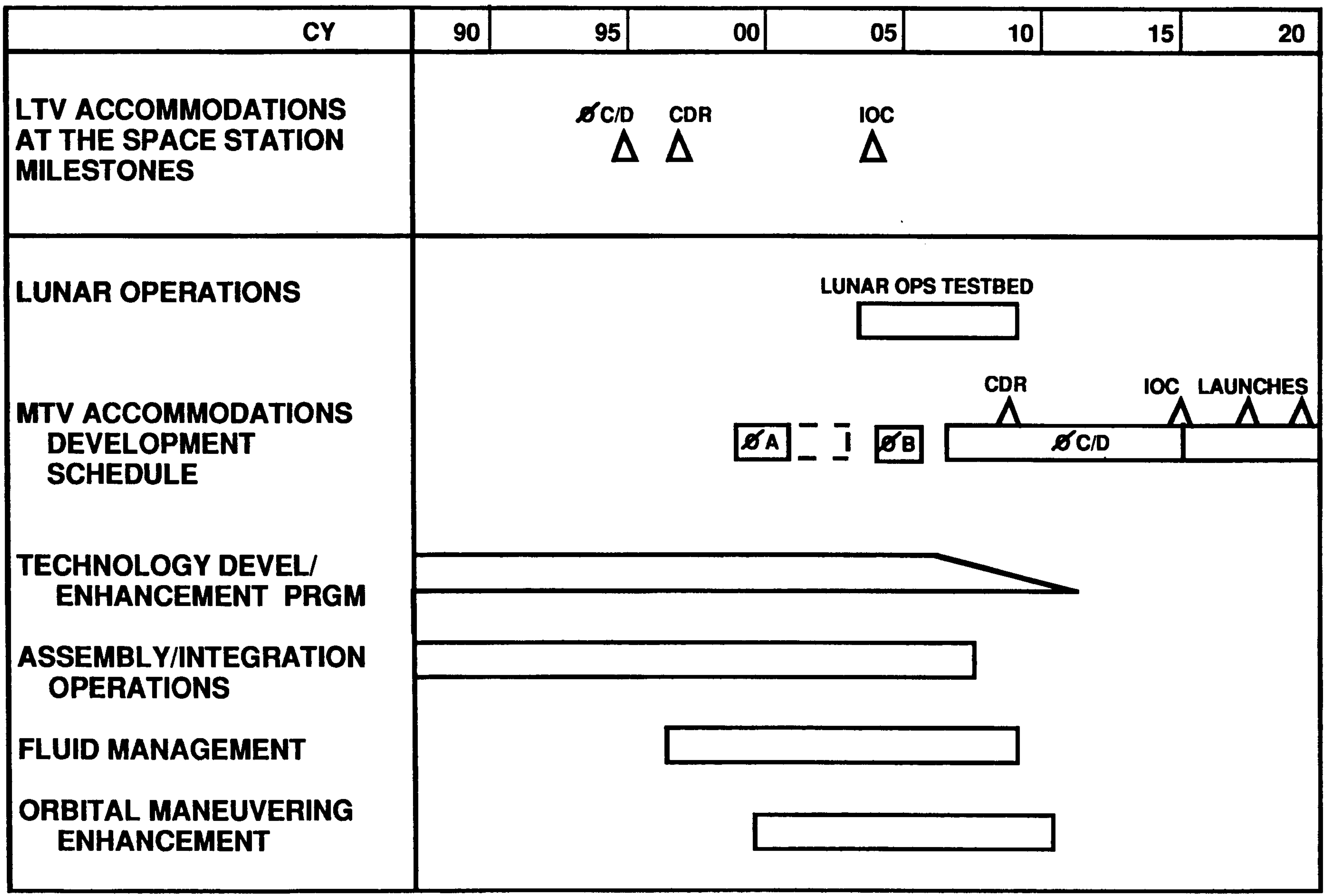
There are a number of technologies which must be developed to support on-orbit MTV accommodations. Most of the technologies needed for accommodation of the MTV will be developed for the Lunar missions, although some enhancements may be required for the MTV. Operating the Lunar missions will provide a base for determining what technology areas need enhancement for accommodation support of Mars missions.

Technology enhancements for the Mars missions are largely a result of the increase in the size of the vehicle, the degree of on-orbit operations, and the duration of vehicle assembly and integration on-orbit prior to launch. The size increase in the MTV tanks over the LTV tanks may require enhancement of several technologies. Technologies associated with storing and integrating the large propellant tanks used by the MTV include thermal control, zero g vent and low g propellant mass gauging, and automated fluid and electrical disconnects.

Ground and flight operations technologies may require enhancement as well, in the areas of teleopration/ robotics, MTV translating, berthing, & rotation equipment, proximity operations, and orbital maneuvering capability.

To support an IOC of 2015 for the MTV, phase A studies for the MTV accommodations support hardware should begin in 1998-1999. Technology development should be currently underway.

MTV ACCOMMODATIONS TECHNOLOGY REQUIREMENTS



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TRANSFER VEHICLE ACCOMMODATIONS AT TRANSPORTATION NODE
Outline

- INTRODUCTION
- REQUIREMENTS
- LUNAR TRANSFER VEHICLE ACCOMMODATIONS
- MARS TRANSFER VEHICLE ACCOMMODATIONS
- CONCLUSIONS

TRANSPORTATION NODE CONCLUSIONS

Basing the LTV accommodations at SSF, man tended or permanently manned free flying platforms are each good options. However, if piloted LTV missions prior to 2004 are desired, SSF deployment and evolutionary capabilities development must be accelerated.

The majority of operations performed on-orbit for assembly, servicing, integration & checkout of the LTV and LEV can be done using teleoperations and robotics. EVA may be required for some tasks, but is generally used as a backup.

Accommodation facilities for a single vehicle appear sufficient to support the proposed flight rates of 1 to 2 per year.

The favored option for MTV accommodations is basing at a free-flying transportation node. Most tasks necessary for assembly and integration of the MTV on-orbit can be done using teleoperation and robotics. EVA may be required for complex tasks and for visual inspection, but is usually used as a backup.

The mass of the MTV, duration of MTV assembly operations, and debris protection requirements create significant impacts to SSF if based there. These impacts include software hooks and hardware scars as well as disturbances to the microgravity environment necessary for many scientific users aboard SSF.

Debris protection is a significant issue for on-orbit accommodations. The size and mass of the debris protection becomes prohibitive if a high probability of no-penetration over time is desired. Innovative methods of providing debris protection may reduce many of the impacts this requirement has on the accommodation design.

TRANSPORTATION NODE CONCLUSIONS

LTV ACCOMMODATIONS

- LTV ACCOMMODATIONS AT SSF, MAN TENDED OR PERMANENTLY MANNED FREE FLYING PLATFORMS ARE GOOD OPTIONS
- SSF DEPLOYMENT AND EVOLUTIONARY CAPABILITIES DEVELOPMENT MUST BE ACCELERATED IF THE FIRST PILOTED LTV MISSION IS PRIOR TO 2004
- MAJORITY OF LTV/LEV ASSEMBLY, CHECKOUT AND SERVICING CAN BE ACCOMPLISHED USING TELEOPERATIONS/ROBOTICS WITH EVA AS BACKUP
- ACCOMMODATION FACILITIES FOR A SINGLE LTV ARE SUFFICIENT FOR LTV FLIGHT RATES OF 1 OR 2 PER YEAR
- DEBRIS PROTECTION IS A SIGNIFICANT ISSUE, AND INNOVATIVE METHODS OF PROVIDING DEBRIS PROTECTION CAN REDUCE IMPACTS ON FACILITIES

MTV ACCOMMODATIONS

- MTV ACCOMMODATIONS AT FREE-FLYING TRANSPORTATION NODE IS FAVORED OPTION
- MASS OF MTV, DURATION OF OPERATIONS, AND DEBRIS PROTECTION REQUIREMENTS CREATE SIGNIFICANT IMPACTS ON SSF, PARTICULARLY ON MICROGRAVITY ENVIRONMENT
- MAJORITY OF MTV ASSEMBLY AND INTEGRATION CAN BE ACCOMPLISHED USING TELEOPERATIONS/ROBOTICS WITH EVA AS BACKUP
- DEBRIS PROTECTION IS A SIGNIFICANT ISSUE, AND INNOVATIVE METHODS OF PROVIDING DEBRIS PROTECTION CAN REDUCE IMPACTS ON FACILITIES

TRANSPORTATION NODE RECOMMENDATIONS

The requirements for a growth OMV capable of supporting LTV and MTV operations should be more fully defined. Concepts for a growth OMV should be formulated based on those requirements, stressing commonality and evolution between LTV and MTV support.

On-orbit accommodation concepts should be developed which emphasize commonality and evolution between LTV and MTV accommodations.

The scope of operations and cost estimates for transportation nodes should be broadened. Included in these estimates should be scheduled spares and consumables requirements and resupply, steady state support from the ground for regular operations, as well as many other considerations.

The impacts to SSF science operations should be more fully explored. Alternative concepts and methods should be developed for providing debris protection.

TRANSPORTATION NODE RECOMMENDATIONS

- FURTHER DEFINE GROWTH OMV REQUIREMENTS AND FORMULATE CONCEPTS WHICH SATISFY THOSE REQUIREMENTS, ADDRESSING COMMONALITY AND EVOLUTION
- EVALUATE ON-ORBIT ACCOMMODATION CONCEPTS WHICH WILL EMPHASIZE COMMONALITY AND EVOLUTION BETWEEN LTV AND MTV ACCOMMODATIONS
- BROADEN THE SCOPE OF OPERATIONS AND COST ESTIMATES FOR TRANSPORTATION NODES TO INCLUDE SCHEDULED SPARES AND CONSUMABLES REQUIREMENTS, STEADY STATE GROUND SUPPORT, AND OTHER CONSIDERATIONS
- CONSIDER FURTHER THE IMPACTS TO SSF SCIENCE OPERATIONS FROM THE ACTIVITIES REQUIRED FOR TRANSPORTATION NODE SUPPORT
- DEVELOP ALTERNATIVE CONCEPTS AND METHODS FOR PROVIDING DEBRIS PROTECTION FOR EXTENDED PERIODS ON-ORBIT